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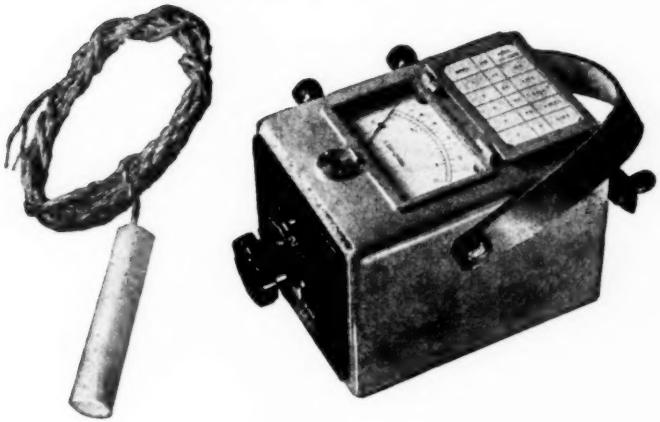

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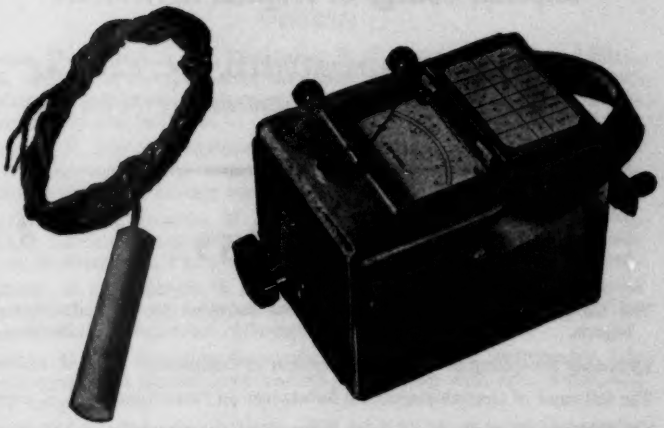

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RHIZOBIUM AFFINITIES OF AFRICAN SPECIES OF TRIFOLIUM

D. O. NORRIS

(C.S.I.R.O. Plant and Soils Laboratory, Division of Plant Industry, Brisbane)

Summary

Eight species of Trifolium from equatorial mountain regions of Africa were tested against a range of strains of Rhizobium derived from clovers of European and Mediterranean origin, in comparison with two strains of Rhizobium derived from African clovers. Cross-inoculation studies were also made between the African Trifolium species and members of the tribe Vicieae. Effective symbiosis was obtained only with an African strain derived from *T. rueppellianum*, but varying degrees of ineffective symbiosis were obtained with strains from clovers of European origin. Ability to cross-inoculate with Pisum, Lathyrus, and Vicia species was demonstrated. The significance of these findings to the plant introduction officer and to the taxonomist is discussed.

THE genus Trifolium contains a little-known group of species inhabiting the high mountain regions of tropical Africa. Gillett [1] has recently summarized available botanical knowledge of these species, together with some notes on their economic importance. Some of them constitute an important part of the pasturage in those regions. Since these species have potential use in sub-tropical and tropical uplands of Australia, particularly in Queensland, the Plant Introduction Section of the Division of Plant Industry, C.S.I.R.O., has on several occasions obtained small samples of seed for trial. These trials have not been successful because effective nodulation could not be obtained. In 1956 all residual seed, together with two strains of Rhizobium from Kenya, was passed to the author to investigate the nodulation requirements of these species.

The primary objective of the work reported in this paper was to elucidate the Rhizobium requirements of the African Trifolium species so that agronomic testing could be done. At the same time opportunity was taken to investigate the cross-inoculation affinities of the group. With this objective five strains of Rhizobium derived from members of the tribe Vicieae were included in the tests. This was done to supplement observations made by Kleczkowska, Nutman, and Bond [2] that Pisum and Trifolium species will sometimes cross-inoculate.

Materials and Methods

Five named species of African Trifolium were tested, together with a further three that were not identified but were known by observation to be different from the first five; they are referred to hereafter as *Trifolium sp. A*, *B*, and *C*. Available data about the Trifolium species tested are shown in Table 1. Details of the Rhizobium strains used are given in Table 2. Data given on effectiveness are based on trials conducted in this laboratory but not reported here. The Rhizobium strains were

[Empire Journ. of Exper. Agric., Vol. 27, No. 106, 1959.]

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TABLE 1. *African Trifolium species tested*

Species	*Serial no.*	*Notes*
T. rueppellianum Fres.	CPI.18245	Received from Veterinary Department, Jakiri, British Cameroons, 4.1.54. Purple-flowered robust plant with low habit. Widespread in Bamenda Hills, 3,400 up to 7,000 ft. or above. Natural growth association with *Sporobolus* spp. Grows excellently with Kikuyu at Jakiri. The heaviest stocking density is on this Sporobolus-clover range.
	CPI.18058	Received from J. B. Gillett, Kew, 29.6.53
	CPI.21155	Received from Grassland Research Station, Kitale, Kenya, 8.5.56.
T. semipilosum Fres.	CPI.16056	Received from Pasture Research Officer, Kabete, Kenya, 14.3.52.
	CPI.17843	Received from R. Strange, Grassland Research Station, Kitale, Kenya, 6.3.53.
	CPI.17844	Ditto.
	CPI.17848	Ditto.
	CPI.21156	Ditto. 8.5.56
T. steudneri Schwf.	CPI.17845	Ditto. 6.3.53.
T. tembense Fres.	CPI.18061	Received from J. B. Gillett, Kew, 29.6.53. Collected near Addis Ababa by J. B. Gillett. An annual more luxuriant than *T. rueppellianum*, but more moisture-demanding. Its economic value is doubtful.
	CPI.20746	Received from Kenya Department of Agriculture, K5252.
T. cheranganiense Gillett	CPI.17846	Received from R. Strange, Grassland Research Station, Kitale, Kenya, 6.3.53.
T. sp. A	CPI.17847	Ditto.
T. sp. B	CPI.18247	Received from Veterinary Department, Jakiri, British Cameroons, 4.1.54. White flower, round leaflet, low habit. Infrequent plant. Collected at Jakiri 8.12.53 at 6,000 ft.
T. sp. C	CPI.18246	Received from Veterinary Department, Jakiri, British Cameroons, 4.1.54. Large red flower, slender plant with narrow leaflets, upright habit. Collected Jakiri 8.12.53. Very frequent at 6,000 ft.

selected to cover both of the 'effectiveness sub-groups' of European clovers as pointed out by Vincent [3]. Although most of the Trifolium strains of Rhizobium used in this study were isolated from their hosts in Australia the convention has been adopted of referring to them as 'European strains', referring to their hosts of origin.

TABLE 2. *Rhizobium Strains used in Testing*

Strain no.	*Origin*	*Effectiveness on:*			
		T. repens	*T. incarnatum*	*T. alexandrinum*	*T. fragiferum*
CB.1	= SU.157, ex *Trifolium repens*	E	I		I
CB.2	= SU.298, ex *T. incarnatum*	I	E		
CB.3	= NA.34 ex *T.* sp.	E	Partly E		E
CB.4	D.S.I.R., N.Z., ex *T. repens*	E	I		I
CB.147	= Rothamsted clover F	E	I	Partly E	E
CB.148	= SU.310, ex *T. repens*	E	I	I	I
CB.149	= SU.297–31, ex *T. incarnatum*	I	Partly E	Partly E	E
CB.219	*T. procumbens* Stanthorpe, Queensland		Partly E	E	E
CB.220	*T. arvense* Stanthorpe, Queensland		I	I	Partly E
CB.325	*T. subterraneum* Gatton, Queensland		E	E	E
CB.370	*T. incarnatum* Beerwah, Queensland		E	E	Partly E
CB.371	*T. incarnatum* " "		E	E	Partly E
CB.372	*T. incarnatum* " "		E	E	Partly E
CB.420	*T. fragiferum* D'Aguilar, Queensland		I	E	I
CB.526	= 58A.6.6 Kenya Department of Agriculture, ex *T. semipilosum*	Not known			
CB.527	= 75C.1.4 Kenya Department of Agriculture, ex *T. rueppellianum*	Not known			
CB.108	*Pisum arvense* Mooloola, Queensland	Effective on *Pisum sativum* and *P. arvense*			
CB.134	*Vicia sativa* Brisbane, Queensland	Ineffective on Vicia			
CB.230	*Vicia sativa* Toowoomba, Queensland	Effective on Vicia			
CB.472	*Lathyrus sylvestris* Strathpine, Queensland	Partly effective on Vicia			
CB.596	*Pisum sativum* = Rothamsted strain VI	Effective on Pisum			

E = Effective. I = Ineffective.

In most samples only very small quantities of seed were available and the germination and viability were poor. Where seed supply was strictly limited first priority was given to testing the species against the two African Rhizobium strains. Where seed was more plentiful the species was tested also against a range of strains from European clover species of importance in agriculture. In several instances where seed was relatively abundant the species was also tested against some or all of five strains of Rhizobium derived from members of the tribe Vicieae. On several occasions seed of more than one line of a particular species were tested simultaneously. Since the reactions of such lines were identical they have been bulked under each species for the presentation of the data.

In Experiments 1, 2, and 3 the plants were grown in sterile vermiculite in flat-bottomed 6 × 1-in. tubes, plugged with cotton wool. These were set in a water bath in the glasshouse, immersed to the level of the surface of the vermiculite. The vermiculite was a horticultural sample that had been treated with a plant nutrient solution of pH 7, drained, leached, and dried. It was saturated with the same plant nutrient solution before planting the seed. Seed was treated 15 minutes in concentrated sulphuric acid, followed by 5 minutes in a solution of calcium hypochlorite, from which it was transferred to sterile filter-paper for germination. Only seed showing signs of viability was transferred to tubes, but despite this some samples yielded very few plants. Three seeds were dropped on to the surface of the vermiculite in each tube. Wherever possible uninoculated control tubes were included, as well as uninoculated nitrate controls. These were provided with ammonium nitrate at a nitrogen rate equivalent to 1 cwt. of ammonium sulphate per acre. Tubes were randomized when set in the water bath in the glasshouse. They were watered once with sterile water during growth.

Experiments 4 and 5 were made in bottle-jar assemblies modified from Leonard [4]. The plants were grown in vermiculite treated as above, in Experiment 4, and in sand in Experiment 5. The sand or vermiculite was soaked with plant nutrient solution of pH 7 and the jars filled with the same nutrient solution before autoclaving. In Experiment 4 seed was treated as for the tube experiments and pricked into the jars after germination. In Experiment 5 it was thoroughly scarified (with the exception of Pisum), sterilized 5 minutes in mercuric chloride, and sown directly into the sand. Uninoculated control jars were provided in Experiment 4, but not in Experiment 5 where uninoculated jars in adjacent experiments served as checks on technique. All jars were randomized in position on greenhouse benches protected from roof-drip by suspended transparent plastic ceilings. With this technique, in which the jars remain untouched during the experiments except for the addition of sterile water to the bottom jar on one or sometimes two occasions, contamination is a rarity. No nodulation occurred in any control jar.

The inoculum used was a strongly turbid bacterial suspension approximately 7 days old, grown in liquid yeast-extract mannitol medium. 0·2 ml. of this was pipetted into each tube and 1 ml. into each jar.

In the subsequent Tables results of nodulation tests are shown as

number of nodules formed on *X* plants out of *Y* plants that were inoculated. Sometimes the nodules were counted, and the actual number present is recorded. At other times they were recorded as F (few = 1 to 5 per plant), M (moderate = 6 to 10 per plant), or N (numerous = > 10 per plant). The effectiveness of the symbiosis as judged by the greenness and vigour of the plants is recorded as E (effective), Partly E (partly effective), Slightly E (slightly effective), or I (ineffective).

Experiment 1 *Result*

Seven African clover species were tested against two Rhizobium strains CB.2, representing the crimson clover effectiveness sub-group, and CB.3, representing the white clover effectiveness sub-group of the

TABLE 3. *Nodules produced on Eight Trifolium Species by Two Rhizobium Strains*

Trifolium species used	*Rhizobium strain used:*				*Control, not inoculated*
	CB.2		*CB.3*		
	Nodules	*Effectiveness*	*Nodules*	*Effectiveness*	
T. rueppellianum .	12 on 5/7	I	11 on 5/8	I	0 on 6
T. semipilosum .	17 on 6/7	I	15 on 7/9	I	0 on 5
T. steudneri . .	4 on 3/3	I	0 on 3	..	0 on 2
T. tembense . .	0 on 1	..	0 on 2	..	..
T. cheranganiense .	4 on 1/1	I	5 on 2/2	I	0 on 2
T. sp. A . .	0 on 2	..	0 on 2	..	..
T. sp. B . .	10 on 3/3	I	5 on 2/3	I	..
T. pratense . .	28 on 7/7	I	22 on 10/10	E	0 on 3

clover cross-inoculation group. Red clover (*T. pratense*) was included for comparison. An attempt was made to have three tubes for each treatment, but defective seed prevented this. Tubes were washed out and examined after 42 days' growth. The results are summarized in Table 3.

Experiment 2

Eight African Trifolium species were tested in vermiculite tubes against twelve Rhizobium strains from European Trifolium species, two strains from African Trifolium species, and three strains from Pisum and Vicia species. Uninoculated control and uninoculated nitrate control tubes were included. Where possible there were three tubes per treatment. They were washed out and examined after 60 days' growth. At the conclusion of the experiment the plants in the nitrate controls and the few tubes in which an effective association occurred were conspicuous by their green vigorous growth, the remainder being small and chlorotic or pigmented. Results are summarized in Table 4.

Experiment 3

Two species *T. cheranganiense* and *T. sp. C*, of which seed was more abundant, were given a more intensive test against four strains of

TABLE 4. *Experiments 2 and 3: Incidence of Nodulation and Effectiveness of Seventeen Rhizobium Strains on Eight Trifolium Species*

Clover species	*Rhizobium strain:* CB. 1	CB. 3	CB. 147	CB. 148	CB. 149	CB. 219	CB. 220	CB. 325	CB. 370	CB. 371	CB. 372	CB. 420	CB. 526	CB. 527	CB. 108	CB. 134	CB. 230	*Control*	*Control* +N
T. rueppellianum CPI.18245 CPI.21155	F on 1/1 I	O on 1	O on 1	F on 1/1 I	F on 1/1 I	F on 7/8 I	F on 8/8 I	F on 5/5 I	F on 5/5 I	F on 2/2 I	F on 1/1 I	O on 2	F on 7/9 I	F on 6/6 E	O on 3	F on 4/4 I	F on 2/2 I	..	O on 3
T. semipilosum CPI.17844 CPI.21156	F on 4/4 I	F on 5/6 I	F on 7/7 I	F on 8/8 I	F on 5/5 I	F on 4/4 I	F on 6/6 I	F on 4/4 I	F on 5/7 I	O on 5	F on 2/3 I	F on 5/6 I	F on 2/2 I	F on 2/2 partly E	F on 2/6 I	F on 1/3 I	F on 1/4 I	O on 8	O on 5
T. steudneri CPI.17845	..	..	O on 3	F on 1/3 I	..	F on 1/2 I	O on 1	..	..	..	..	O on 1	..	F on 1/1 E					
T. tembense CPI.20746	..	..	..	..	..	..	..	..	..	..	..	..	N on 1/1 I	M on 2/2 E					
T. cheranganiense CPI.17846	N on 7/7 I	F to N on 20/20 I	F to N on 8/8 I	F to M on 7/7 I	F to M on 10/10 I	..	N on 4/4 I	F to M on 8/8 I	F to N on 13/13 I	F on 6/6 I	M on 7/7 I	F to M on 6/6 I	F to N on 13/13 I	O on 13	O on 9	..	..	O on 2	O on 1
T. sp. A CPI.17847	..	..	..	..	..	..	..	..	..	..	..	..	F on 1/1 I	F on 5/5 E					
T. sp. B CPI.18247	..	..	..	..	..	..	..	..	..	..	..	..	F on 5/5 I	F on 3/3 I	..	..	..	O on 3	
T. sp. C CPI.18246	F on 9/9 I	F on 27/27 I	F on 9/9 I	F to M on 9/9 I	F on 9/9 I	F on 10/10 I	F on 14/14 I	F on 7/7 I	F on 36/36 I	F on 11/11 I	F on 12/12 I	F to M on 10/10 I	F to M on 32/32 I	F on 31/31 E	O on 10	F on 7/10 I	F on 7/8 I	O on 13	O on 10

Rhizobium, CB.3 and CB.370, chosen to represent the two effectiveness sub-groups of European clovers, and the two African strains CB.526 and CB.527. Five tubes of each species were inoculated with each strain and grown for 45 days. Since the results did not differ from those of Experiment 2 they have been included in Table 4.

Experiment 4

Twenty bottle-jar assemblies were planted, five each with *T. repens*, *T. incarnatum*, *T. rueppellianum* (CPI.21155), and *T. semipilosum* (CPI.21156), and thinned to four plants per jar. One jar of each species

TABLE 5. *Experiment 4: Nodulation of Four Trifolium Species by Four Rhizobium Strains*

Clover species	*Nodulation and effectiveness with Rhizobium strain:*				*Control not inoculated*
	CB.3	*CB.370*	*CB.526*	*CB.527*	
T. semipilosum CPI.21156	F on 4/4 I	F on 4/4 I	N on 4/4 I	M on 4/4 Slightly E	O on 4
T. rueppellianum CPI.21155	F on 4/4 I	F on 4/4 I	M on 4/4 I	M on 4/4 E	O on 4
T. repens	M on 4/4 E	N on 4/4 Slightly E	M on 4/4 I	O on 4	O on 4
T. incarnatum	N on 4/4 Slightly E	M on 4/4 E	M on 4/4 I	M on 4/4 I	O on 4

was inoculated with each strain of Rhizobium, and one jar was left uninoculated as a control. The Rhizobium strains used were as in Experiment 3. Plants were washed out and examined after 95 days' growth. At this time the plants of *T. repens* inoculated with CB.3, *T. incarnatum* inoculated with CB.370, and *T. rueppellianum* inoculated with CB.527 were large, green and vigorous, and effectively nodulated. Those of *T. semipilosum* inoculated with CB.527, *T. incarnatum* inoculated with CB.3, and *T. repens* inoculated with CB.370 showed slight growth. The remainder were small and chlorotic, or pigmented like the controls. The results are summarized in Table 5.

Experiment 5

In a final experiment the cross-inoculation affinities of certain clover species and members of the tribe Vicieae were examined in more detail than in Experiment 2. Two jars were used for each treatment. The following species were planted:

Pisum arvense var. Dunkfield
Vicia sativa
Lathyrus ochrus
Trifolium repens var. Irrigation
T. incarnatum var. Dixie
T. rueppellianum, CPI.21155
T. semipilosum, CPI.21156

Rhizobium strains CB.526, CB.527, CB.147, and CB.325 ex Trifolium

species were inoculated to Pisum, Vicia, and Lathyrus; and Rhizobium strains CB.108, CB.596, CB.134, CB.230, and CB.472 from species in the tribe Vicieae were inoculated to Trifolium species. After 57 days there was no evidence of N-fixation in any plant, all of which were small and chlorotic or pigmented. Results of the examination of roots are summarized in Table 6.

The nodules formed in this experiment were mostly ½–1 mm. in diameter and white or green in colour. On *Trifolium repens* there were also many that were described as 'rudimentary', that is, they were just recognizable as nodular swellings, being less than 0·5 mm. in diameter.

The Rothamsted strain CB.147 ex Trifolium, produced nodules on some plants of Pisum, Lathyrus, and Vicia, whereas strains CB.526 and CB.325 produced nodules only on Pisum and strain CB.527 could nodulate none of them. The isolates from Pisum, Vicia, and Lathyrus showed surprising ability to nodulate Trifolium species. *T. rueppellianum* was particularly heavily nodulated.

Discussion

The results of all experiments make it clear that the African species of Trifolium tested have little symbiotic affinity with European Trifolium species. Of the eight African clover species not one showed any ability to produce an effective nodulation with strains of Rhizobium derived from European clovers. The African strain CB.527, derived originally from *T. rueppellianum*, produced effective, or partly effective nodulation on *T. rueppellianum*, *T. semipilosum*, *T. steudneri*, *T. tembense*, *T. sp. A*, and *T. sp. C*, but it was ineffective on *T. sp. B* and was quite unable to nodulate *T. cheranganiense*. The other African strain, CB.526, was ineffective on *T. rueppellianum*, *T. semipilosum*, *T. tembense*, *T. cheranganiense*, *T. sp. A*, *T. sp. B*, and *T. sp. C*.

Definite ability to cross-inoculate with members of the tribe Vicieae was shown in two experiments. These experiments provide food for thought on the subject of cross-inoculation grouping. The clover cross-inoculation group has been regarded as one of the best examples of the concept. However, as pointed out by Vincent [3], there exist within the clover group two effectiveness sub-groups. It is quite common for a strain of Rhizobium to be effective on one clover species and quite ineffective on another. The phenomenon of effectiveness is something quite separate from that of infectiveness, and must be disregarded when considering questions of cross-inoculation affinities. From this point of view, data such as those from Experiments 2 and 5 present a problem. If the African strain CB.527 had not been available one would have been undecided whether to assign *T. rueppellianum* and *T. sp. C* to the 'Pea cross-inoculation group' or to the 'Clover cross-inoculation group', since they perform equally well with strains from clovers and with strains from Vicia and Lathyrus species. But since strain CB.527 effectively nodulated six of the African clover species, and in Experiments 4 and 5 was unable to nodulate Pisum, Vicia, or Lathyrus but did nodulate European Trifolium species, one might deposit *T. rueppellianum* and *T. sp. C* in the 'clover cross-inoculation group'. If the African strain

TABLE 6. *Experiment 5: Nodules produced by Cross-inoculation of Rhizobium Strains ex tribe Trifolieae and tribe Vicieae*

Species inoculated	*Nodules produced by Rhizobium strain:*								
	CB.526	*CB.527*	*CB.147*	*CB.325*	*CB.108*	*CB.596*	*CB.134*	*CB.230*	*CB.472*
Pisum arvense . .	5 on 2/12	0 on 12	Numerous on 12/13	6 on 3/11					
Vicia sativa . .	0 on 48	0 on 33	5 on 4/31	0 on 40					
Lathyrus ochrus . .	0 on 10	0 on 10	2 on 1/11	0 on 12					
Trifolium repens .	..	..	..	..	Numerous rudiments on 4/18	Numerous rudiments on 2/11	7 on 4/13	4 rudiments on 2/13	3 plus rudiments on 3/10
T. incarnatum . .	..	..	..	..	0 on 12	4 plus rudiments on 4/10	41 on 5/14	19 on 5/10	3 on 1/7
T. semipilosum . .	..	..	..	..	2 on 1/18	11 on 5/16	13 on 4/21	27 on 5/19	5 on 3/18
T. rueppellianum .	..	..	..	..	29 on 5/18	7 on 1/11	50 on 5/20	34 on 2/13	138 on 7/18

CB.526 alone had been tested this means of escape would not have been available. *T. cheranganiense*, which was unable to nodulate with the African strain CB.527 but nodulated ineffectively with European strains ex clover, provides a further dilemma. These dilemmas are resolvable only if one takes a broad viewpoint on cross-inoculation grouping. The author has pointed out previously [5] that the restricted cross-inoculation group is very probably a degenerate derivative from the ancestral condition which was one of cross-inoculation promiscuity. The 'clover cross-inoculation group' has been formulated as a result of the study of a comparative handful of species of European and Mediterranean origin, which constitute such a specialized group. If a study had been made of the whole genus Trifolium, including African and American species, no emphasis would have been placed on this group because no compact group would have been demonstrated, but instead probably a number of small groups of varying size showing varying degrees of specialization.

It is highly probable that as more Trifolium species are tested greater amounts of cross-inoculating ability with members of the tribe Vicieae will be discovered. The relationship of the Rhizobium from Trifolium and from Pisum goes deeper than mere ability to cross-inoculate. Definite serological relationship has been shown by A. Kleczkowski and Thornton [6], and susceptibility to the same strains of phage has been shown by J. Kleczkowska [7]. A logical explanation for this is that there exists a close evolutionary connexion between the tribe Vicieae and the tribe Trifolieae. As was pointed out previously [5], these two tribes stand out from the rest of the Leguminosae because they are essentially temperate and adapted to high levels of Ca and P nutrition. To a great extent also their geographic distributions overlap. The chromosome data of Senn [8] indicate that the Trifolieae are an ancient stock with the basic chromosome number $n = 8$, which he considers to be the primitive condition in Leguminosae. They have developed very greatly in recent times in Mediterranean regions. There exist also within the tribe hypoploids with $n = 7$, in particular within the section Chronosemium. The basic chromosome number in the tribe Vicieae, which taxonomists agree is comparatively 'new', and which Senn states is a 'closely related group morphologically and karyologically', is $n = 7$. It is not beyond the bounds of possibility that this tribe is derived from a 7-chromosome hypoploid of the Trifolieae stock and not, as Senn assumed, from a more distant 8-chromosome primitive member of the Papilionaceae. Such an origin might explain observed relationships between the Rhizobium associated with the two tribes. A detailed study of Rhizobium relationships between Vicieae and Trifolieae, with particular reference to taxonomic affinities, might be very rewarding, but there is little point in such work being undertaken in Australia.

The practical implication of this work is that no good purpose will be served by trials of introduced African Trifolium species in Australia, or probably elsewhere, unless effective Rhizobium strains derived from these species in their native environment are used to inoculate them. The chances are remote that they will pick up a useful strain from amongst

those strains already present and derived from introduced European Trifolium species.

REFERENCES

1. J. B. Gillett, *Kew Bull.*, 1952, No. 3, 367.
2. J. Kleczkowska, P. S. Nutman, and G. Bond, *J. Bact.*, 1944, **48**, 673.
3. J. Vincent, *Proc. Linn. Soc., N.S.W.*, 1954, **79**, 371.
4. L. T. Leonard, *U.S.D.A. Circ.*, 1944, **703**.
5. D. O. Norris, *Empire J. Expt. Agric.*, 1956, **24**, 247.
6. A. Kleczkowski and H. G. Thornton, *J. Bact.*, 1944, **48**, 661.
7. Janina Kleczkowska, *Canad. J. Microbiol.*, 1957, **3**, 171.
8. H. A. Senn, *Bibliog. Genet.*, 1938, **12**, 175.

THE GROWTH OF LEGUMES IN CONJUNCTION WITH PHOSPHATE FERTILIZER, AS A MEANS OF INCREASING AND STABILIZING SOIL FERTILITY AND AGRICULTURAL PRODUCTIVITY, IN GREECE

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Summary

The results of experiments carried out in Greece over a period of 8 years are summarized in this paper.

Wheat was grown alternately with various annual legumes in rotation, with the application of nitrogen and phosphorus fertilizers to the legumes only.

Marked increases in yield of legumes were obtained with superphosphate, and the yield of the following wheat crop was also improved; the legume seed showed an increased content of protein and P_2O_5 while there were also indications of an increased protein content in the following wheat crop. Nitrogen fertilizer, however, gave no improvement in the yield or composition of the legumes, or in the yield of the following wheat crop.

The responses to superphosphate of the legumes used in these experiments, and the yield responses of the following wheat crops, varied for the different legume species.

The content of organic matter and nitrogen in the soil on which the legumes had been grown with superphosphate was increased.

ECOLOGICAL conditions in Greece, as in many other parts of the world with a similar climate, are generally unfavourable to increased agricultural production. From the total land area of 13,256,000 hectares, only about 1,000,000 is in the main fertile plains. Only some 10 per cent. of cultivated land is irrigated, and plant growth is frequently hindered by lack of adequate rainfall.

Precipitation is irregular and usually insufficient to meet the needs of intensive growth in spring and summer. At the same time evaporation is high, and generally reaches a peak when rainfall is lowest. A 7-year average annual rainfall at Larissa was 497 mm., of which 321 mm. (65 per cent.) fell between 1 September and 28 February, while the corresponding figure for evaporation was 948, of which 672 mm. (71 per cent.) occurred between March and August.

The soils are mostly rather shallow and of low fertility. Erosion, particularly during the torrential winter storms, is a serious problem on the mountain slopes. These conditions combine to give a soil with very low content of organic matter—usually below 1 per cent. compared with the more usual 3 to 4 per cent. found in most soils of U.S.A. and northern Europe [1]. In consequence, nitrogen is very deficient in most soils in Greece.

A recent survey by the Organization for European Economic Co-operation [2] has shown that an average of about 13 kg. of nitrogen per

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hectare is used annually on the cultivated land in Greece. Recent work by Swanson [1] has suggested that 25·1 lb. of nitrogen per acre is usually removed by crops each year, and up to a further 24·2 by erosion. There is thus likely to be a continuous deficit of nitrogen, and this is undoubtedly a limiting factor to increased crop production.

Since 1933, research in Greece has been directed towards the development of a more balanced rotation than the traditional mono-cultural system, and the author [3, 4, 5, 6] has reported on various aspects of this work. In particular, efforts have been made to show how legumes may be used to improve the forage resources, and how more balanced rotations may improve soil productivity. The Statistical Yearbook of Greece [7] and figures quoted by Petropoulos [8] show that the area of annual legumes expressed as a percentage of the total area of annual crops has increased from 2·9 per cent. in 1929 to 7·8 per cent. in 1956, while the area of fallow has fallen from 557,295 hectares in 1929 to 240,000 hectares in 1955.

This paper reports on experiments which began in 1946 with the object of showing how far legumes could contribute by reducing the nitrogen deficit, and whether the application of phosphates to the legume in the rotation could adequately replace the use of fertilizer nitrogen.

Review of Literature

Many workers have reported upon the effects of legumes in increasing the nitrogen available in soils. Russell [9] reviewed this aspect in detail, and Browne [10] has made an historical review of some of the earlier work in this field.

Some attempts have been made to estimate the amount of nitrogen which is fixed in soils by the symbiotic bacteria [e.g. 1, 11, 12, 13]. Donald and Williams [14] have shown how nitrogen fixation can be increased by the application of phosphorus fertilizers to legumes. They found that under Australian conditions 85 lb. of nitrogen was added to the top acre/4 inches of soil by rhizobial activity for every 1 cwt. of superphosphate applied. Similarly, Davies [15] concluded that for every 1 kg. of phosphorus added an additional 4·75 kg. of nitrogen was accumulated.

Another source of nitrogen in the soil is humus. Middleton [16] and Kursanov [17] have demonstrated the value of decomposing organic matter in this respect, and Joffe [11] has estimated that up to 20 per cent. of the total nitrogen requirement may be obtained from this source.

Experimental Details

The experiments were conducted at the State Experimental Station at Larissa, situated in the plain of Thessaly somewhat south of latitude 40° N., at a height of 76 metres above sea-level.

The climate is dry-to-subhumid mesothermal, with wide fluctuation of both daily and seasonal temperature and with limited and unevenly distributed annual rainfall. Table 1 gives the relevant data for weather conditions during the 8-year period 1949–57.

TABLE 1. *Average Weather Conditions during the 8-year Period 1949–57 at Larissa*

Month	*Mean air temp. °C.*	*Absolute min. air temp. °C.*	*Absolute max. air temp. °C.*	*Rainfall, mm.*
September	24·0	6·5	39·0	16·7
October	16·6	1·5	33·4	101·5
November	11·3	−5·0	25·6	87·5
December	7·2	−5·5	21·5	52·6
January	5·7	−9·2	20·0	58·4
February	7·5	−8·6	23·5	48·3
March	9·1	−6·0	31·0	48·3
April	14·5	−1·0	31·0	33·0
May	19·8	4·0	36·5	44·3
June	25·9	7·0	43·0	39·2
July	28·7	11·0	44·0	14·0
August	28·2	14·0	43·2	10·4

The soil is a typical plains soil of east Thessaly and there is an insignificant slope (0·35 per cent.). The following are the relevant details:

Soil type	Chernosemic
Clay:	51·6 per cent.
Silt:	18·4 per cent.
Sand (0·2 to 0·05 mm.):	28·2 per cent.
pH:	6·7 (subsoil dominantly alkaline)
N:	0·86 mg. per cent.
P_2O_5:	2·86 mg. per cent. (2, Dirks)
K_2O:	51·7 mg. per cent. (4·65, Dirks)
Organic matter:	1·08 per cent.

Biologically the soil represents a poor source of organic material.

The experimental area was first laid out in November 1949. Each plot was 10 square metres (2 × 5 m.) separated by an uncultivated border of 0·8 m. with 2-m. pathways between the rows of plots. The following treatments were used:

Rotation 1. Wheat alternating with Vetch (*Vicia sativa*)
" 2. " " " Bitter vetch (*Ervum ervilia*)
" 3. " " " Grass pea (*Lathyrus cicera*)
" 4. " " " Forage pea (*Pisum arvense*)
" 5. " " " Edible pea (*Pisum sativum*)
" 6. " " " Broad beans (*Vicia faba*)
" 7. " " " Lentil (*Ervum lens*)
" 8. " " " Chick pea (*Cicer arietinum*)

The hard-wheat variety 'Limnos' was used throughout.

Each rotation was replicated twenty-four times to allow each of the following six fertilizer treatments to be applied on four of the replicates:

Fo	Control—no fertilizer
F1	30 kg. N per hectare (N_1)
F2	30 kg. P_2O_5 per hectare (P_1)
F3	30 kg. N+30 kg. P_2O_5 per hectare (N_1P_1)
F4	30 kg. N+60 kg. P_2O_5 per hectare (N_1P_2)
F5	60 kg. P_2O_5 per hectare (P_2)

These fertilizer treatments were applied only to the legume in the rotation, and the wheat had no fertilizer.

Nitrogen was applied as ammonium nitrate–calcium carbonate (20·5 per cent. N), and phosphorus as superphosphate (16·0 per cent. P_2O_5).

Both seed and fertilizer were sown in early November, the legumes by hand and the wheat by a seed drill.

Each year a detailed record was kept of the establishment and growth of the plots to maturity. At harvest the produce of each plot was weighed before threshing, and again, after threshing, as grain and straw. The grain was sampled for determination of moisture content and subsequent chemical analysis where appropriate.

Results

It is obviously not possible in a summary paper such as this to give all the detailed figures, or to review every aspect of the data. The complete data have been lodged in the Library of the State Experimental Station at Larissa, where they are available to be consulted.

The yield results for broad beans (Rotation 6) in 1955 are summarized in Table 2. These illustrate the general finding that the most important yield differences (from control) were obtained from the fertilizer treatments containing phosphorus.

TABLE 2. *Yields of Broad Beans in 1955 (per stremma*)*

Fertilizer treatment	*Seed*		*Haulm*	*End of flowering*	
	Yield, kg.	*% Increase over control*	*Yield, kg.*	*Date*	*Average height, cm.*
Fo (Control)	153	..	196	2 May	69
F1 (N_1)	182	19	249	3 ,,	71
F2 (P_1)	272	79	413	3 ,,	81
F3 (N_1P_1)	280	83	396	2 ,,	80
F4 (N_1P_2)	329	115	403	2 ,,	82
F5 (P_2)	362	137	475	2 ,,	89
Min. sig. diff. (P = 0·05)	27				

* 1 stremma = ¼ acre approx. or $\frac{1}{10}$ hectare.

Table 3 shows the analysis of variance of the yield data summarized in Table 2. It is apparent that the major effect was from the P_1 treatment (simple application of 30 kg./ha. P_2O_5). The double dressing of P_2O_5 (P_2) has not been proportionally more effective.

TABLE 3. *Analysis of Variance, for Mean Yields of dry Seed of Broad Beans, in kg. per 1/10 hectare as summarized in Table 2*

	Value of F	*F value for* P = 0·05
Blocks	8·46	3·29
Fertilizer treatments	80·38	2·90
F1 (30 units N)	0·02	4·54
F2 (30 units P_2O_5)	383·52	4·54
F3 (30 units N+30 units P_2O_5) . .	11·65	4·54
F4 (30 units N+60 units P_2O_5) . .	0·34	4·54
F5 (60 units P_2O_5)	6·38	4·54

Similar effects were noted in the wheat yields in the various rotations, and Table 4 shows a typical analysis of variance for the yields of wheat in the same year (1955), following forage pea (Rotation 4).

TABLE 4. *Analysis of Variance, for Mean Yields of dry Wheat Grain, in kg. per 1/10 hectare, following Forage Pea (Rotation 4) in the year 1955*

	Value of F	*F value for* P = 0·05
Blocks	0·06	3·29
Fertilizer treatment . . . . (for preceding legume crop)	2·90	2·90
F1 (30 units N)	1·61	4·54
F2 (30 units P_2O_5)	11·62	4·54
F3 (30 units N+30 units P_2O_5) . .	0·75	4·54
F4 (30 units N+60 units P_2O_5) . .	0·47	4·54
F5 (60 units P_2O_5)	0·07	4·54

The average results for the three treatments: Control, N_1, and P_1 have been summarized for all the crops over 8 years in Table 5, with the M.S.D. (minimum significant difference) in each case.

In every case the application of 30 kg. P_2O_5 per hectare has given a significant increase in yield of legume grain. The application of 30 kg. N per hectare, however, has shown no significant increase in yield, and in most cases the yield has been lower, although not significantly so.

For the wheat yields the results have been closely parallel, and it is evident that the residual effect of the phosphate, presumably in part through stimulation of the legume, has been reflected in a significantly higher wheat yield in most of the rotations, although in a few cases the difference, though positive, was not significant. The most marked results have been obtained following broad beans and edible peas. Nitrogen applied to the legume had no significant effect on the following wheat crop.

Analysis of the harvested legume seed was made in the year 1955 by the Biochemical Laboratory of the Hellenic Agricultural Research Station. Some of the results of this analysis are recorded in Table 6. The application of 30 kg. P_2O_5 per hectare to the legume (P_1) has in most cases

TABLE 5. *Mean Yields of Dry Grain (8-year average) Obtained from Treatments Fo, F1, and F2 on the Different Rotations*

In kg. per 1/10 hectare

Rotation no.	*1*		*2*		*3*		*4*		*5*		*6*		*7*		*8*	
Crop	*Vetch*	*Wheat*	*Bitter vetch*	*Wheat*	*Grass pea*	*Wheat*	*Forage pea*	*Wheat*	*Edible pea*	*Wheat*	*Broad beans*	*Wheat*	*Lentil*	*Wheat*	*Chick pea*	*Wheat*
Fertilizer treatment (applied to legume only)																
Fo (Control) .	119·6	174·4	91·2	170·3	163·1	164·5	76·2	171·1	29·1	165·3	97·0	156·8	107·4	175·4	134·7	162·3
F1 (30 units N) .	100·2	165·3	76·5	170·4	166·4	168·7	70·3	186·4	37·7	170·4	96·9	169·6	104·8	178·3	111·3	156·3
F2 (30 units P_2O_5) .	152·1	190·2	122·4	176·3	199·2	179·3	120·5	185·1	65·1	186·5	170·9	194·9	122·0	192·2	164·3	174·6
M.S.D. (P = 0·05) .	24·0	16·3	20·5	16·9	16·9	10·7	16·5	19·0	15·2	14·1	39·1	5·8	13·3	16·9	24·2	12·6

TABLE 6. *Analysis of Seed of Different Legumes for Pure Protein and P_2O_5, with Different Fertilizer treatments (Per cent. in Dry Matter).*

Legume	Fertilizer treatment	Pure protein	P_2O_5 %
Vetch	Nil	27·1	0·70
,,	N_1	28·7	1·01
,,	P_1	28·9	0·84
,,	P_2	29·0	1·06
Bitter vetch	Nil	25·4	0·68
,, ,,	N_1	24·7	0·65
,, ,,	P_1	26·6	0·78
,, ,,	N_1P_1	25·7	0·74
,, ,,	N_1P_2	26·4	0·97
,, ,,	P_2	27·1	0·99
Grass pea	Nil	23·4	0·56
,, ,,	P_1	25·5	0·63
,, ,,	N_1P_1	27·6	0·84
,, ,,	N_1P_2	27·3	0·84
,, ,,	P_2	27·5	0·94
Forage pea	Nil	25·0	0·56
,, ,,	N_1P_1	27·9	0·84
,, ,,	P_2	28·5	1·06
Edible pea	Nil	25·9	0·72
,, ,,	N_1	24·6	0·61
,, ,,	P_1	26·8	0·92
,, ,,	N_1P_1	25·3	0·79
,, ,,	N_1P_2	23·5	1·08
,, ,,	P_2	26·3	1·20
Broad beans	Nil	25·4	0·69
,, ,,	N_1	26·8	0·70
,, ,,	P_1	26·8	0·79
,, ,,	N_1P_1	26·8	0·78
,, ,,	N_1P_2	27·1	0·88
,, ,,	P_2	27·8	0·89
Lentil	Nil	25·1	0·64
,,	N_1	25·6	0·66
,,	P_1	28·0	0·95
,,	N_1P_1	26·5	0·74
,,	N_1P_2	27·6	1·03
,,	P_2	27·5	0·85
Chick pea	Nil	19·6	0·66
,, ,,	N_1	18·9	0·59
,, ,,	P_1	21·8	0·81
,, ,,	N_1P_1	20·4	0·70
,, ,,	N_1P_2	22·5	0·92
,, ,,	P_2	21·8	0·81

given an increase in the content of pure protein and P_2O_5 in the harvested seed.

On the other hand the application of 30 kg. of N per hectare (N_1) has had little or no effect; for the chick-pea, bitter vetch, and edible pea the content of protein and P_2O_5 was even less than in the control.

At the higher levels of application of fertilizer—N_1P_1, N_1P_2, and P_2—the main effects were again presumably due to the phosphorus fertilizer.

Some of the wheat harvested in July 1950 was submitted to analysis at the Chemical Laboratory of the Ministry of Commerce, Greece. These results (Table 7), however, being from only one year's crop, must be treated with reserve.

TABLE 7. *Analysis of Wheat, following Rotation with Edible Peas, Broad Beans, and Chick Pea in 1950*

Rotation	*Fertilizer applied to legume*	*Crude protein %*
Wheat, following edible pea	Nil	9·5
" " "	N_1	10·9
" " "	P_1	13·5
" " broad beans	Nil	13·9
" " "	N_1	14·4
" " "	P_1	14·4
" " chick pea	Nil	12·8
" " "	N_1	13·2
" " "	P_1	13·4

The beneficial effect of rotation with legumes, with different fertilizers, in increasing the content of organic matter and nitrogen in the soil, is shown in Table 8.

TABLE 8. *Average Content of Organic Matter and Nitrogen, from the Analysis of Ninety-two Samples of Soil taken on 5 July 1955, after Harvest (analysed by the Chemical Soil Laboratory of Salonica).*

Fertilizer treatment (on legume only)	*Organic matter, % for soil under:*		*No. of samples*	*Nitrogen % for soil under:*		*No. of samples*
	Legumes	*Wheat*		*Legumes*	*Wheat*	
Nil	1·05	1·08	7	0·087	0·096	7
N_1	1·03	1·11	8	0·095	0·095	7
P_1	1·13	1·20	8	0·098	0·091	7
N_1P_1	1·10	1·00	8	0·098	0·092	8
N_1P_2	1·18	1·13	8	0·100	0·097	8
P_2	1·18	1·14	8	0·102	0·092	8

Discussion

The results have clearly shown the value of phosphorus fertilizer under these conditions in increasing the yield of annual legumes. It does not appear that high applications of phosphorus fertilizers are always likely to give an economic return, and the F2 treatment—30 kg. of P_2O_5 per hectare—is probably somewhere near the optimum. The phosphorus fertilizer also increased the percentages of protein and of P_2O_5 in the seed of the legumes, when the normal uptake of P was not hindered by drought or other physiological factors.

The application of nitrogen to the legumes has been of no benefit either to the legumes or to the following wheat crop.

The stimulation of the legume by the application of phosphorus fertilizer has been reflected in the following wheat crop, although there were differences in the efficiency of the different legumes: broad beans and peas gave greater increases in the yield of the following wheat crop than the other legumes included in these experiments. There were also indications that the grain of a wheat crop, grown after a legume which had received phosphorus fertilizer, had a higher protein content. This could be related to the increased content of organic matter and nitrogen which was found in the soil in which the legumes treated with phosphorus fertilizer had been grown.

The experimental results summarized in this paper have strikingly demonstrated the great potential value, in Greece, of the symbiotic nitrogen fixation associated with the growth of legumes in conjunction with superphosphate, in stabilizing soil fertility, thus increasing both the yield and the nutritive value of the legume crops; improving the content of organic matter and nitrogen in the soil; and giving improved crops of wheat grown in rotation with legume crops so treated, with much potential benefit to the whole national economy and the general health of the people.

REFERENCES

1. C. L. W. Swanson, *Soil Fertility*, in *Handbook of Food and Agriculture*, New York, F. C. Blank, 1955, p. 27.
2. Organisation for European Economic Co-operation, *Fertilisers*, 1954–7, Paris, 1957.
3. D. A. Panos, *Der Züchter*, 1939, **11**, 341.
4. —— ibid., 1940, **12**, 295.
5. —— *J. Brit. Grassland Soc.*, 1950, **5**, 1.
6. —— *Agron. J.*, 1954, **46**, 109.
7. Anon., *Statistical Yearbook of Greece*, 1956, Athens, National Printing Office, 1956, p. 119.
8. S. Petropoulos, *Rept. of Governor, Agric. Bank of Greece, 1956*, Athens, 1957, p. 14.
9. E. J. Russell, *Soil Conditions and Plant Growth*, 8th edition, London, Longmans, 1953, p. 594.
10. C. A. Browne, *A Source Book of Agricultural Chemistry*, Waltham, Mass., Chronica Botanica Co., 1944.
11. J. S. Joffe, *The ABC of Soils*, New Brunswick, N.J., Pedology Publications, 1949, p. 8.
12. W. A. Wheeler, *Forage and Pasture Crops*, New York, Van Nostrand Co., 1950, p. 140.
13. Anon., *Rural Research in CSIRO*, 1954, **8**, 1.
14. C. M. Donald and C. H. Williams, *Austral. J. Agric. Res.*, 1954, **5**, 664.
15. J. Griffiths Davies, *O.E.E.C., Suppl. to Fatis Review*, 1955, p. 42.
16. H. E. Middleton, in *Soil Physical Conditions and Plant Growth*, by B. T. Shaw, New York, Academic Press, 1952, p. 31.
17. A. L. Kursanov, *Ann. Rev. Plant Physiol.*, 1956, **7**, 405.

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THE GROWTH AND APPETITE OF SHEEP ON HIGH-FIBRE LOW-PROTEIN DIETS SUPPLEMENTED WITH UREA AND MOLASSES

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Summary

In 8 weeks forty-eight 2½-year-old Corriedale wethers fed with a ration of poor-quality oat straw, supplemented with urea and molasses, lost on the average significantly less weight and ate significantly more straw than forty-eight similar sheep fed with the straw only.

It was not found possible to improve the effect of the supplement by adding sodium sulphate, vitamin B complex, ethyl alcohol, or all of these, or by replacing the urea with sodium nitrate.

The appetites and live-weights of sheep fed with grass and clover hay were not improved by the addition of urea and molasses.

The results of a digestibility trial showed that the supplementation of straw by urea and molasses did not improve the digestibility of the dry matter, the crude fibre, or the ether extract, of the ration. It did, however, improve markedly the apparent digestibility of the crude protein.

DURING the months of low rainfall sheep in Australia commonly lose weight when grazing non-irrigated pastures. In South Africa, where apparently similar conditions occur, it has been reported that animals grazing pastures that are high in fibre and low in protein are more productive if the standing feed is sprayed with a solution of urea and molasses.

Although many experiments have been carried out on the utilization of urea by ruminants since Zuntz [1] first suggested that ruminant synthesis of protein from sources of non-protein nitrogen was possible, comparatively little work has been done with the aim of improving the nutrition of animals under range conditions. Some workers, however, have used basal experimental rations with a low-protein content.

Table 1 shows how the plane of nutrition in the authors' experiment compares with that in other recent work.

Willman, Morrison, and Klosterman [2] obtained no greater gain in the live-weight of lambs when they added urea to a ration of corn, corn silage, and hay. Pope, Gallup, and Whitehair [3] found that lambs retained less nitrogen from urea as the proportion of roughage (cotton-seed hulls) in their diet increased, and that with a fixed proportion of roughage the digestion of the fibre improved with increasing amounts of urea in the diet. Tillman and Swift [4] found a slightly higher protein digestibility and an increased nitrogen retention in lambs receiving urea than in those receiving soybean oil meal as supplements to basal rations containing timothy and lucerne hay.

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Peirce [5] found a 32 per cent. increase in wool production and a slight increase in body-weight when urea was added to a basal ration low in protein and high in starch, but not when added to a ration higher in protein and deficient in starch. Franklin, Briggs, and McClymont [6] found that a supplement of wheat, urea, and sodium sulphate was of more benefit than one of wheat alone as measured by the survival rate, body-weight, and wool production of sheep on a basal diet comparable to that used in the experiment now reported.

TABLE 1. *Planes of Nutrition in Some Recent Experiments, as Determined by the Non-Urea Constituents of the Rations*

Reference	*Approximate weight of D.M. of total ration (gm.)*	*Approximate crude protein of basal ration* (%)
Willman *et al.*, 1946 [2]	830	8·5
Pope *et al.*, 1950 [3]	630	7·0
Tillmann *et al.*, 1953 [4]	840	9·0
Peirce, 1951 [5]	Up to 1,150	7·0
	,, 750	5·0
Franklin *et al.*, 1955 [6]	Up to 480	2·4
	,, 570	3·5
This paper	,, 960	2·2

Clark, Oyaert, and Quin [7] found that starvation or diets low in protein increased susceptibility to urea poisoning. To sheep on grass hay a dose of 10–15 gm. of urea caused ruminal paresis, but to sheep on lucerne hay 20 gm. was needed. Peirce, Moule, and Jackson [8] found that sheep grazing a low-protein pasture died after consuming either 36 gm. of urea in about 1 hour, or a total of 30 gm. in two drenches an hour apart, or 25 gm. in a few minutes. These findings and the review of McNaught and Smith [9] stress the danger of dosing in a short time or instantaneously as in drenching, and show the need to let ingestion be as gradual as possible.

Three experiments are now reported. The first two were feeding trials to show: (*a*) whether the appetites and live-weights of sheep fed with straw only were affected by a supplement of urea and molasses; and (*b*) whether utilization of this supplement could be improved by adding to it sodium sulphate, ethyl alcohol, or the vitamin B complex. The third experiment was a digestibility trial to determine whether the ingestion of the urea and molasses supplement affected the digestibility of the basal ration.

Experiment No. 1

Procedure and Methods

Ninety-six Corriedale wethers, approximately 2½ years old, were used for this experiment. They were weighed on 23 July 1956, and drenched with 5 ml. of a mixture of 3 parts of carbon tetrachloride to 2 of paraffin. On 30 July they were divided into eight groups each of twelve sheep, and each group was enclosed in a yard approximately 0·1 acre in size. There was a similar distribution of live-weights throughout the groups. The sheep, all of which had previously been together at pasture, grazed

the yards closely and the experimental basal ration of milled oat straw was gradually introduced until 9 August, when the experiment began. By then no herbage was left in the yards and the soil had been broken up with a rotary hoe, which was used from time to time to ensure that the yards remained free of herbage.

The sheep were weighed twice weekly. Food was given daily between 9 and 10 a.m. in weighed amounts. On the following morning residues were collected and weighed.

The experiment ended on 7 October 1956.

TABLE 2. *Analysis of Diets Used in Experiment No. 1*

Diet	*Crude protein* %	*Ether extractive* %	*Crude fibre* %	*Ash* %	*Moisture* %	N-*free extractive* %
Straw only .	2·2	1·6	34·7	6·0	6·4	49·1
Straw, urea, and molasses* .	5·5	1·7	33·2	6·6	6·9	46·1

* 10 gm. urea and 38 gm. molasses to 1 lb. of straw.

Diet. Groups 1, 3, 5, and 7 were given the basal diet of oat straw only which had been hammer-milled through a ¾-in. screen.

Groups 2, 4, 6, and 8 were given the hammer-milled oat straw to which had been added urea and molasses dissolved in water. The solution was introduced in increasing amounts from 9 to 13 August, and from then the additions were at the rate of 5 gm. of urea to a pound of straw, or approximately 1·1 per cent., and 4 per cent. of molasses. After 10 September these rates were doubled to 10 gm. of urea to a pound of straw and 8 per cent. of molasses, and they remained at this level until the end of the experiment. Food and water were offered without stint to all groups. The analyses of the diets are given in Table 2.

Results

General health. All the sheep remained in good health and there were no apparent digestive disturbances. Early in the experiment one sheep in group 3 (straw only) became highly nervous during the weighing operations and sometimes could not stand up in the weighing cage. It appeared normal at other times, however, and towards the end of the experiment this symptom disappeared. Its body-weight did not appear to be affected.

Live-weight and appetite. Fig. 1 shows live-weight and appetite changes. It is noticeable that the live-weight graphs of the two treatments show similar patterns, though at different levels. Climate was thought to be a factor which might have caused this, since all the sheep were similarly exposed to changes in the weather. A study of wind, temperature, and rainfall records showed, however, that these factors could not account for the daily variations in food intakes and live-weights that were common to all groups. The high average food intake by the urea-fed sheep on an isolated occasion, the 34th day, is due to an

increase in two groups whose interest in the food was stimulated by work being done near the food troughs.

The results of statistical analyses of the food intake and live-weight records are given in Table 3.

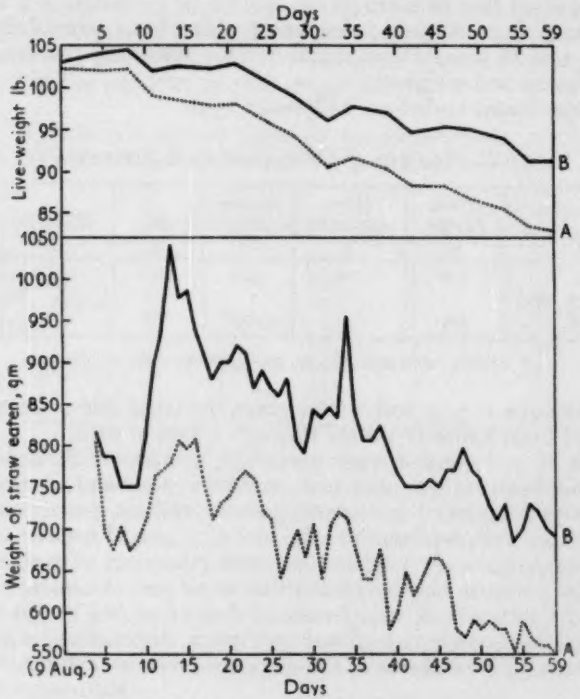

FIG. 1. Live-weights (above) and amounts of straw eaten (below) for sheep receiving straw only (A) and straw plus urea and molasses (B). (Experiment No. 1.)

Experiment No. 2

A perusal of the literature suggested various ways in which the utilization of the urea-molasses supplement might be improved.

When Clark and Quin [10] obtained comparable results to those now reported, viz. an average live-weight loss in 7 weeks of 11·8 lb. in sheep fed with hay only and 3·1 lb. in sheep fed with hay and urea, they suggested that the level of protein or of specific amino-acids in their basal diet was insufficient. Such deficiencies are highly probable in the basal diet of the present experiment. These workers also suggested that sodium nitrate may be a more effective supplement than urea. Anderson and Rapp [11] suggested that an important function of certain dietary amino-acids is to provide reducing conditions in the rumen, favouring an increased synthesis of amino-acids from urea, but concluded that such

TABLE 3. *Results of Statistical Analyses of Changes in Live-weight and Food Intake per Sheep in Experiment No. 1*

	Initial weight, lb.*	*Weight loss,* lb.*	*Total feed consumption, lb.*
No urea . . .	102·3	19·3	83·6
Urea	103·3	12·0	101·9
Difference . . .	..	7·3	18·3
Difference for significance $P = 0.05$	..	6·0	16·0
Difference for significance $P = 0.01$	..	9·1	24·2

* For statistical purposes the initial weight was taken as the mean of the first two weighings and the final weight as the mean of the last two weighings.

conditions could be achieved more efficiently by feeding ethyl alcohol. Thomas *et al.* [12] kept lambs on a purified diet in which urea was almost the only source of nitrogen, and found that survival rate, body-weight, and wool production markedly improved when inorganic sulphates were added. Tosic [13] found loss of appetite in some of a group of sheep fed with only fibrous hay, and cured them by dosing with yeast extract. He pointed out that this effect could have been due to one or other member of the vitamin B complex or to trace elements or both, which are known to be present in yeast, but suggested that it was probably due to a vitamin.

The basal diet of the present experiment therefore might have been improved by the addition of protein, inorganic sulphate, members of the vitamin B complex, or ethyl alcohol. It was decided to run an exploratory experiment to test these various treatments.

Procedure and Methods

The same sheep were used as in the first experiment, but as one from each group had been withdrawn for use in the digestibility trial (see Experiment No. 3), only eighty-eight were available. As before, these were allocated to groups 1 to 8, on the basis of live-weight, but now also in such a way that each group contained as nearly as possible equal numbers of sheep from each of the two previous treatments.

From the end of the first experiment on 7 October until the beginning of the second on 22 October groups 1 and 2 were fed with milled hay only and groups 3 to 8 with milled straw and molasses only. The general procedure was the same as in Experiment No. 1. The experiment ended on 19 December 1956.

Diet. The diets are shown in Table 4. In Experiment No. 1, because the urea was added in constant proportion to the fodder, the amount of urea ingested fell as appetite fell; therefore, in case appetite continued to fall, the urea was added in constant amount per sheep in Experiment No. 2.

Results

Table 5 shows live-weight and appetite changes.

Groups 1 and 2. Urea and molasses gave no benefit when added to the

hay. This result is comparable with that of Peirce [5], whose work showed that sheep fed with urea added to a high-protein diet grew no faster than others fed with hay only.

Groups 3 to 8. There was no statistically significant difference in either food intakes or live-weight changes between any two groups.

TABLE 4. *Basal Rations, and Daily Allowances per Sheep, of the Various Supplements Fed in Experiment No. 2*

Group	*Basal ration*	*Nitrogen supplement*	*Molasses*	*Other supplements*
1	Grass and clover hay*	None	None	None
2	,,	10 gm. urea	38 gm.	None
3	Oat straw†	,,	,,	None
4	,,	,,	,,	2·5 gm. sodium sulphate
5	,,	,,	,,	0·8 gm. vitamin B complex‡
6	,,	,,	,,	50 ml. absolute ethyl alcohol
7	,,	,,	,,	2·5 gm. sodium sulphate 0·8 gm. vitamin B complex‡ 50 ml. absolute ethyl alcohol
8	,,	10 gm. sodium nitrate	,,	None

* Hammer-milled through 1-in. screen. Crude protein 11·2 per cent., crude fibre 25·3 per cent.

† Hammer-milled and of same stock as in Experiment No. 1.

‡ Containing 3·5 mgm. thiamine, 5·5 mgm. riboflavin, 34·0 mgm. niacin, 32·0 mgm. pantothenic acid, 4·0 mgm. pyridoxine, and 1·0 mgm. cobalt sulphate.

Group 3 was the nearest to being significantly better than any other group, its rate of weight-loss of less than ½ lb. a week per sheep being about half that of the others.

Experiment No. 3

This experiment was a digestibility trial to determine whether the ingestion of urea and molasses affected the digestibility of the basal ration.

Procedure and Methods

This experiment ran concurrently with Experiment No. 2. A preliminary selection was made of eight sheep, one from each group in the first experiment. The live-weight performance of each sheep selected was the closest to the average performance of its group. The sheep continued to receive the same diets as previously, and after observation of individual appetites, two sheep (those on each diet whose appetite differed most from the average) were discarded.

For 5 days before the trial started the sheep wore harness, and for the last 3 days they also wore canvas faecal-collection bags, and were penned. The pens measured approximately 6×4 ft., and were so constructed that the sheep could see each other. Sawdust on the floor absorbed the urine.

Sheep Nos. 1, 2, and 3 were fed with supplemented straw, and Nos. 5,

TABLE 5. *Changes in Average Live-weight and Intake of Roughage per Sheep in Experiment No. 2**

Group	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Treatment	*Hay*	*Hay, Urea, Molasses*	*Straw (S), Urea (U), Molasses (M)*	*S.U.M. and Sulphate*	*S.U.M. and Vit. B complex*	*S.U.M. and Alcohol*	*S.U.M., Sulphate, Vit. B complex, and Alcohol*	*Straw, Nitrate, and Molasses*
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
Live-weight 22.10.1956 .	99·3	101·4	83·4	84·0	82·7	82·0	83·6	84·9
,, 13.12.1956 .	118·0	119·5	80·5	77·0	75·0	75·3	78·0	78·9
Difference . . .	+18·7	+18·1	−2·9	−7·0	−7·7	−6·7	−5·6	−6·0
Average daily intake (gm.) of roughage per sheep								
First week . . .	1,496	1,499	656	666	648	555	559	604
Last week . . .	1,894	1,891	720	643	610	604	658	609
Difference . . .	+398	+392	+64	−23	−38	+49	+99	+5

* Apart from the hay/straw difference, none of the differences between treatments is statistically significant.

6, and 7 were fed with straw only. The trial lasted 10 days, with a lag of 2 days in the collection of faeces to allow for the passage of food through the alimentary tract. After the fifth day sheep No. 5 escaped from its pen and consumed some green fodder. It was therefore discarded.

Starting at 9 a.m. every day faecal-collection bags were changed, food residues collected, and fresh water was given without stint. Food was given at midday.

Preparation and Sampling of Food and Faeces

Drying of food offered, residues, and faeces, for the determination of their dry matter, was at 100° C. for 24 hours; drying for storage and subsequent chemical analysis was all done at 45° C. for 48 hours.

Diet of straw only. All the straw which was necessary for the entire period was hammer-milled through a ¾-in. screen, thoroughly mixed, and sampled in triplicate by quartering. These samples were regarded, for chemical analysis, as representing the food offered daily to sheep Nos. 5, 6, and 7 throughout the trial, daily samples being taken for dry-matter determination.

Diet of supplemented straw. Hammer-milled straw was mixed every day with a solution of urea and molasses. The total weight of added liquid was adjusted by the addition of water so that it equalled the weight of straw; this had been the procedure followed in the previous period as it was convenient for calculations and resulted in even distribution of the supplements without excessive dampness. Two representative samples were taken from the mixture each day, one for determination of dry matter and the other for chemical analysis.

Food residues. Of each sheep's daily residue, half was dried for dry-matter determination and half was dried and kept for chemical analysis.

Faeces. The total daily faeces of each sheep was weighed and two representative samples were taken. On one sample the dry matter was determined and from this the total dry matter in the day's collection was calculated. Of the other sample, dried at 45° C., the required amount was taken to provide dry matter equal to 4 per cent. of the total dry matter in the day's collection. These ten daily aliquots were ground and bulked for chemical analysis.

Results

Table 6 shows the results of analyses of the two diets, the total amount, and the digestibility of each constituent eaten by each sheep.

Discussion of Results

In Experiment 1, regression of weight-loss on feed consumption showed that a rise of 1 lb. in consumption reduced the loss by 0·35 lb., and that the whole of the reduced loss of weight was due to increased feed consumption in those groups fed with the urea and molasses supplement. However, although the urea-fed sheep ate about 20 per cent. more straw than the controls and lost only 60 per cent. as much live-weight they still lost an average of 1·5 lb. per sheep per week.

In Experiment 2 the average rate of loss of all sheep in groups 3 to 8—0·9 lb. per week—was less than in Experiment No. 1, 1·6 lb. per week. A regrouping of results according to the previous treatment (in Experiment 1) showed a tendency for the sheep previously on straw only to lose less weight than those previously on supplemented straw. In particular in group 3 those previously on straw only actually maintained their weight throughout the experiment, while the others lost an

TABLE 6. *Composition of Diets; Intakes and Digestibilities of Constituents (Experiment 3)*

		Dry matter	*Crude protein*	*Ether extract*	*Crude fibre*	*Ash*
Straw* %		93·2	2·2	1·9	34·7	6·0
Sheep 5.	Intake, gm.†	2,602·7	61·8	52·2	966·3	166·9
	Digestibility, %	45·5	−53·1	56·1	40·3	38·8
Sheep 6.	Intake, gm.	3,629·5	88·8	78·3	1,351·5	234·0
	Digestibility, %	46·2	−53·4	59·9	44·5	33·7
Sheep 7.	Intake, gm.	5,668·5	132·2	117·6	2,125·3	360·1
	Digestibility, %	44·9	−59·1	60·0	42·0	37·8
Mean‡	Intake, gm.	4,834·5	148·2	100·1	1,803·1	309·3
	Digestibility, %	45·5	−55·2	58·7	42·9	36·8
Straw, urea, molasses§ %		93·0	5·4	1·8	34·2	6·7
Sheep 1.	Intake, gm.	7,250·0	423·9	140·7	2,587·4	512·9
	Digestibility, %	42·5	31·9	68·0	36·4	34·1
Sheep 2.	Intake, gm.	4,970·1	297·0	94·5	1,780·6	363·4
	Digestibility, %	46·7	39·2	66·5	41·4	40·8
Sheep 3.	Intake, gm.	5,985·3	351·0	109·4	2,149·8	431·0
	Digestibility, %	46·5	35·6	58·7	42·9	39·7
Mean	Intake, gm.	6,068·5	357·3	114·9	2,172·6	435·8
	Digestibility, %	45·2	35·6	64·4	40·2	38·2

* Average of three samples. † 5 days only. ‡ Corrected for sheep No. 5.
§ Average of ten daily samples dried at 45° C.

average of 6 lb. each. But although this difference was consistent for all the groups it was not statistically significant. From these observations it could be inferred that the live-weights of the animals were approaching the level at which they could be maintained on the diet given.

It is not surprising that, in Experiment 3, the sheep on unsupplemented straw of such a low protein content showed a negative apparent digestibility of protein, as it is likely that the metabolic faecal nitrogen far exceeded the dietary nitrogen. The 35·6 per cent. positive apparent digestibility in the sheep on supplemented straw indicates that a considerable proportion of the urea nitrogen was digested.

It is of interest to apply the regression formula worked out by French, Glover, and Duthie [14], $y = 70 \log x - 15$, in which y is the apparent digestibility of crude protein and x is the amount of crude protein in the diet. It was claimed that this equation applies to all rations which have a range of crude protein contents from 2 to 29 per cent., and French [15] confirms that it is valid for rations containing urea. In this way it may be calculated that the apparent digestibility of crude protein in the straw

would be 9·0 and in the supplemented straw 36·8 per cent. The latter agrees well with the figure obtained from this experiment, but the former diverges widely.

In any attempt to discover the true digestibility by calculating metabolic faecal nitrogen from total dietary dry matter, the factor used would have an unusually large influence on the result because such a large proportion of the faecal nitrogen is of metabolic origin in the conditions of this experiment.

Blaxter [16] mentions a factor of 0·5 gm. of metabolic faecal nitrogen per 100 gm. of dry-matter intake, but, because of the high fibre content of the ration used, the figure might be higher in this experiment. However, if this factor is used, the true digestibility of crude protein for sheep Nos. 5, 6, and 7, on unsupplemented straw, appears as: 78·5, 74·3, and 74·8 per cent., and in sheep Nos. 1, 2, and 3, on supplemented straw, as 84·1, 91·3, and 88·9 per cent.

Certain of these results—notably the ineffectiveness of supplementing urea with sodium sulphate, vitamin B complex, or ethyl alcohol—are contrary to recommendations made by other workers, whilst the general lack of response to urea feeding, except with animals primarily maintained on a ration of poor-quality cereal straw, also suggests limits to the value of urea feeding except in special circumstances.

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REFERENCES

1. N. Zuntz, *Pflügers Arch.*, 1891, **49**, 483.
2. J. P. William, F. B. Morrison, and E. W. Klosterman, *Cornell Univ. Agric. Expt. Stat. Bull. No. 834*, 1946, pp. 24 and 56.
3. L. S. Pope, W. D. Gallup, and C. K. Whitehair, *J. Anim. Sci.*, 1950, **9**, 664.
4. A. D. Tillman and R. W. Swift, ibid., 1953, **12**, 201.
5. A. W. Peirce, *Austral. J. Agric. Res.*, 1951, **2**, 435.
6. M. C. Franklin, P. K. Briggs, and G. L. McClymont, *J. Austral. Inst. Agric. Sci.*, 1955, **21**, 216.
7. R. Clark, W. Oyaert, and J. I. Quin, *Onderstepoort J. Vet. Res.*, 1951, **25**, 73.
8. A. W. Peirce, G. R. Moule, and M. N. S. Jackson, *Queensland J. Agric. Sci.*, 1955, **12**, 107.
9. Mary L. McNaught and J. A. B. Smith, *Nutr. Abstr. and Rev.*, 1947, **17**, 18.
10. R. Clark and J. I. Quin, *Onderstepoort J. Vet. Res.*, 1951, **25**, 93.
11. P. C. Anderson and Janet L. C. Rapp, *Feed Service Corp. Comm.*, 1957, **2**.
12. W. E. Thomas, J. K. Loosli, H. H. Williams, and L. A. Maynard, *J. Nutr.*, 1951, **43**, 515.
13. J. Tosic, *Brit. J. Nutr.*, 1949, **3**, 234.
14. M. H. French, J. Glover, and D. W. Duthie, *J. Agric. Sci.*, 1957, **48**, 379.
15. —— ibid., 384.
16. K. L. Blaxter, *Ruminant nutrition*, in *Progress in the Physiology of Farm Animals*, Ed. J. Hammond, London, Butterworths, 1954, vol. 1, p. 3.

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MANURING OF COTTON IN WEST PAKISTAN[1]
I. EFFECT OF THE PRECEDING CROP ON THE YIELD OF SEED COTTON

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Summary

Cotton was sown after gram grown with and without superphosphate, Egyptian clover grown with and without superphosphate, toria, wheat, wheat following guar as green manure, and winter fallow, at five different localities representing cotton varietal zones. Generally, cotton succeeding fallow or legumes gave the better results. The most economic rotation was cotton following Egyptian clover grown with superphosphate while the same rotation without superphosphate was the next best.

COTTON is the most important cash crop of West Pakistan; but there will be a substantial reduction in the exportable surplus when the target spindlage of 2 millions is achieved by the end of 1958, resulting in an estimated home consumption of 1·5 million bales. Therefore, it was planned to increase cotton production from 1·5 to 2·5 million 392-lb. bales per annum by the end of 1958, with an immediate target of 2 million bales.

Manuring is known to be one of the quickest methods of increasing yields. Therefore, a comprehensive plan was prepared to study the various aspects of the problem of manuring of cotton in various varietal zones. Amongst the factors studied were the effect of previous crops, organic and inorganic manures alone and in combination, irrigation, spacing, date of sowing, varieties, and localities. As the yields of crops may be profoundly affected by the preceding crops, the effect of some of the more common crops on cotton yields and economics was studied.

Review of Literature

The rotation of crops plays an important role in the system of crop husbandry. Though much work has been done in other countries [1, 2, 3, 4, 5, 6], there are almost no published data available in Pakistan. However, there are several rotations including cotton [7, 8], viz. wheat and cotton–fallow (2-year rotation); wheat–toria (*Brassica campestris*)–cotton; guar (*Cyamopsis psoraloides*) as green manure followed by wheat–toria–cotton; wheat–fallow–cotton; wheat–gram–cotton; sorghum, guar and gram–cotton and senji (*Melilot parviflora*)–wheat; wheat–cotton–sugarcane (all 3-year rotations), wheat–wheat–toria–cotton; wheat after guar buried–toria–cotton–wheat; wheat–wheat–gram–cotton (all 4-year rotations); and wheat–fallow–wheat–toria–cotton; wheat–wheat or gram–maize and senji–sugarcane–cotton; and wheat–fallow–wheat–sorghum,

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guar and gram–cotton (all 5-year rotations). Egyptian clover (*Trifolium alexandrinum*) may be substituted for gram in all the rotations. The choice of rotation is primarily governed by market prices.

Material and Methods

All these experiments were conducted at Lyallpur, Wazirkot, Montgomery, Khanewal, and Multan, using L.S.S., 238F, and 124F varieties of cotton. Lyallpur and Wazirkot fall in the same varietal zone (L.S.S.); Montgomery falls in the 238F zone; Khanewal and Multan fall in the 124F zone. Cotton was to follow gram (with and without 50 lb. P_2O_5 per acre), Egyptian clover (with and without 50 lb. P_2O_5 per acre), toria or Indian rape, wheat, wheat following guar as green manure, or winter fallow. The experiment was laid out in a randomized block design with six replications, the plot size being $\frac{1}{40}$ acre. Phosphorus was applied, 2 weeks before sowing Egyptian clover and gram, as superphosphate, in furrows and covered with soil. Guar was sown in April and turned in in August to permit sufficient time for its decomposition before sowing wheat in November. The composition of the soils at the various sites is given in Table 1.

TABLE 1. *Chemical Composition and Textural Class of Soils used (air-dry basis)*

No.	*Centre*	*Textural class*	*Total soluble salts*	*pH (1:2·5)*	*Organic matter*	*Total N*	*Total P_2O_5*	*Total K_2O*
			%		%	%	%	%
1.	*Lyallpur* (L)*							
	Block A	Sandy loam	0·10	8·1	0·79	0·05	0·19	0·54
	Block B	,,	0·12	8·0	0·74	0·04	0·20	0·60
2.	*Wazirkot* (W)							
	Block A	Sandy loam	0·17	8·1	0·78	0·13	0·17	0·57
	Block B	..	..	..	..	..	..	..
3.	*Montgomery* (Mo)							
	Block A	Sandy loam	0·11	8·3	0·64	0·04	0·19	0·59
	Block B	,,	0·19	8·1	0·75	0·04	0·21	0·65
4.	*Khanewal* (K)							
	Block A	Loam	0·16	8·3	0·66	0·04	0·17	0·56
	Block B	Sandy loam	0·13	8·2	0·77	0·04	0·21	0·56
5.	*Multan* (Mu)							
	Block A	Sandy loam	0·18	8·3	0·93	0·05	0·22	0·54
	Block B	,,	0·11	8·3	0·89	0·05	0·15	0·63

* The experimental centres are referred to in Table 2 by their initial letters as in parentheses in this table.

Total soluble salts, pH values, and the particle-size distribution were determined by conductivity, electrometric (using glass electrode) and pipette methods respectively. Organic matter was determined by Walkley-Black's method [9]. Total P_2O_5 and total K_2O were estimated from the HCl extract following the details described by Piper [10]. Total nitrogen was determined by the A.O.A.C. method [11].

At the start, the experiments were laid out in Blocks A. Guar was sown in April on the appropriate plots and ploughed-in in August. Toria was sown in September, wheat in November, and gram and Egyptian clover in October. Toria was harvested in January, and wheat and grams in April. Three to four cuttings of the clover were taken. These treatments were followed by cotton at all the localities without disturbing the layout. For the next cotton crop, the crops preceding cotton were grown in Blocks B, so that the third cotton crop was again raised in Blocks A and the fourth in Blocks B.

Several observations were made during growth and after harvest. The data collected are given in the tables below. The data were examined statistically by the analysis of variance.

Experimental Results and Discussion

Table 1 shows that the soils selected were fairly similar in texture and chemical composition so that as far as possible soil variation should not add to the other variable factors. The results of the experiments, in yields of seed cotton, are shown in Table 2.

At Lyallpur, Wazirkot, Montgomery, and Khanewal data were available for only three years. The effect of previous crops was highly significant for all three years at Lyallpur, and for two years at Wazirkot, Montgomery, and Khanewal. At Multan, in the results for all four years, the effect was significant in two years. It is noteworthy that during 1953/4, when these trials were started, the differences in yield for different preceding crops were not significant, except at Lyallpur, and this was also the case at two centres in 1954/5. It seems that the cropping and management of the land prior to the starting of these experiments had a dominating effect on the first crop grown thereafter.

To get a general picture of the yields, average yields of seed cotton for the four years are given in Table 3. At Lyallpur, fallow, Egyptian clover grown with 50 lb. P_2O_5 per acre, and gram grown with 50 lb. P_2O_5 per acre gave best results in that order. At Wazirkot this sequence was changed to fallow, gram with P_2O_5, and Egyptian clover without P_2O_5. At Montgomery, the order of best treatments was fallow, Egyptian clover with P_2O_5, and Egyptian clover without P_2O_5. At Khanewal there was a significant change in the picture. Here the order of topmost treatments was clover with P_2O_5, Egyptian clover without P_2O_5, gram with P_2O_5. At Multan the sequence was: Egyptian clover with P_2O_5, fallow, and gram without P_2O_5.

Generally, taking the results for all five centres together, highest yields of seed cotton were obtained when cotton succeeded fallow. The treatment which gave the next best yields was cotton following Egyptian clover with P_2O_5, while gram with P_2O_5 and the Egyptian clover without P_2O_5 were close thirds. It is very noteworthy that the worst treatment, cotton following wheat, is a common practice in the Punjab. It is also noteworthy that toria, which is generally considered to be an exhausting crop, was better than wheat or wheat following green manuring with guar.

The pooled analyses of the data show that the effect of the preceding

TABLE 2. *Yearly Average Yields of Seed Cotton in Maunds* per Acre*

No.	Preceding crop	1953–4				1954–5					1955–6					1956–7	
		L	*Mo*	*K*	*Mu*	*L*	*W*	*Mo*	*K*	*Mu*	*L*	*W*	*Mo*	*K*	*Mu*	*W*	*Mu*
T_1	Gram with 50 lb. P_2O_5 per acre	19·11	7·21	8·96	15·16	22·09	15·30	17·82	18·32	16·99	16·84	15·15	13·45	8·58	13·33	14·10	7·67
T_2	Gram without P_2O_5	14·83	7·71	7·70	15·84	22·53	14·97	17·84	16·63	16·94	17·41	12·77	13·81	7·81	13·23	13·31	7·89
T_3	Egyptian clover with 50 lb. P_2O_5 per acre	17·19	7·90	8·29	16·19	24·08	14·91	20·57	22·53	16·44	18·58	10·82	14·11	9·69	16·04	15·78	8·89
T_4	Egyptian clover without P_2O_5	16·65	7·35	8·64	15·45	22·83	15·09	18·08	18·81	14·91	17·60	11·93	15·04	9·25	13·34	15·39	8·78
T_5	Toria or Indian rape	14·04	6·80	6·93	15·21	22·66	15·67	16·94	15·47	17·54	16·39	11·30	11·92	6·28	10·36	10·94	7·12
T_6	Guar green-manured–wheat	13·47	9·23	7·75	13·75	18·38	11·89	11·14	13·70	15·31	17·35	13·77	14·54	9·08	11·64	11·56	6·56
T_7	Wheat	22·58	6·59	7·52	15·59	20·08	11·56	14·03	15·06	14·12	15·29	13·26	11·44	6·21	9·11	7·54	5·89
T_8	Fallow	16·83	8·36	8·34	15·54	24·49	17·19	24·70	16·74	18·15	20·02	18·91	18·31	9·46	15·79	13·60	8·84
	Least significant difference, P = 0·05	4·16	N.S.	N.S.	N.S.	3·07	N.S.	3·34	3·72	N.S.	2·24	2·68	2·20	1·65	2·17	2·21	1·56

* One maund = 82·5 lb. N.S. = not significant.

crops on cotton yields was highly significant at three centres, but not significant at two (Wazirkot and Multan).

Similarly the effect of years was highly significant at three centres, but not significant at two (Montgomery and Khanewal).

TABLE 3. *Average Yields of Seed Cotton, 1953–7, in Maunds per Acre*

Treatments (see Table 2)	*Centres*				
	Lyallpur (3 years)	*Wazirkot (3 years)*	*Montgomery (3 years)*	*Khanewal (3 years)*	*Multan (4 years)*
T_1	19·35	14·85	12·83	11·95	13·29
T_2	18·25	13·68	13·12	10·71	13·48
T_3	19·95	13·84	14·19	13·50	14·64
T_4	19·03	14·14	13·49	12·23	13·13
T_5	17·69	12·64	11·85	9·56	12·56
T_6	16·40	12·41	11·64	10·18	11·82
T_7	19·32	10·79	10·69	9·59	11·18
T_8	20·45	16·56	17·12	11·51	14·58
Least significant difference, P = 0·05 (pooled analysis)	1·41	N.S.	1·43	1·37	N.S.
Least significant difference, P = 0·05 (effect of years)	0·81	1·17	N.S.	N.S.	0·95

Crop planning is prompted by the need for economic gains. It is therefore worth while to calculate the economics of crops in these experiments.

The average yields of the crops preceding cotton are given in Table 4.

TABLE 4. *Average Yields of Crops preceding Cotton in Maunds per Acre*

Treatments	*Crop*	*Localities*				
		Lyallpur	*Wazirkot*	*Montgomery*	*Khanewal*	*Multan*
T_1	Gram (grain	21·80	19·80	26·70	15·52	19·00
T_2	" "	20·30	17·06	25·40	14·37	16·95
T_3	Clover (fodder)	963·00	697·00	923·00	618·20	784·10
T_4	" "	813·00	586·00	746·80	509·30	784·10
T_5	Toria (Indian rape) (seed)	12·00	10·75	11·52	9·25	9·18
T_6	Wheat (grain)	24·00	23·56	21·94	23·19	25·00
T_7	" "	22·75	21·50	19·28	24·69	20·75

Average net income per acre from seed cotton alone, and from seed cotton together with the preceding crops, is given in Table 5. The cost of growing each crop was taken into consideration and all the calculations were made on the basis of current market prices.

With all the treatments the highest returns from seed cotton were obtained at Lyallpur, and the lowest at Khanewal. At Wazirkot and Multan the returns were closely similar and at Montgomery they were somewhat lower. Except at Khanewal, cotton succeeding fallow gave the highest returns.

However, to get a complete picture, the total net income from seed cotton and from the crops preceding it is also given in Table 5. At all the centres the highest total net income was obtained from cotton following Egyptian clover which received 50 lb. P_2O_5 per acre, followed by cotton grown after Egyptian clover grown without P_2O_5. The

TABLE 5. *Income in Rupees* per Acre*

Treatments (see Table 2)	*Net income from seed cotton alone*					*Net income including preceding crop*				
	Lyallpur	*Wazirkot*	*Montgomery*	*Khanewal*	*Multan*	*Lyallpur*	*Wazirkot*	*Montgomery*	*Khanewal*	*Multan*
T_1	544·65	378·45	304·04	260·03	332·15	631·75	389·29	280·06	443·27	444·19
T_2	517·70	335·26	314·92	219·37	335·65	624·90	407·01	263·15	476·74	407·87
T_3	576·22	341·76	353·29	308·39	366·43	870·65	651·50	430·32	628·16	503·19
T_4	542·73	354·39	328·79	266·49	325·77	798·36	566·96	370·28	551·32	496·52
T_5	501·53	294·72	271·04	180·99	304·49	604·04	360·76	238·52	368·45	377·81
T_6	451·87	302·75	262·79	201·51	275·41	583·58	419·91	322·83	369·80	429·13
T_7	526·56	238·49	232·29	192·13	259·65	666·33	375·40	347·40	320·30	361·92
T_8	995·47	441·21	449·92	245·21	374·03	601·47	380·03	251·21	445·92	447·21

* One rupee = $0·21 or 1s. 6d.

superiority of these treatments depended on the good yields of seed cotton and the high income from the green fodder. Generally, cotton following toria was the least profitable. The incomes from the other treatments varied from place to place.

Other observations recorded were germination counts, number of plants per acre at maturity, plant height at maturity, number of nodes and internodes, percentage seed maturity, percentage of ginning outturn, number of mature bolls per plant, and the weight of seed cotton per boll.

The statistical analyses show that, whereas the rest of these factors were not affected by the preceding crops, the number of mature bolls and the weight of seed cotton per boll were affected by the nature of the preceding crop, and these were the factors which contributed towards the higher yields.

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REFERENCES

1. A. W. Klemme and O. T. Coleman, *Mo. Agric. Expt. Sta., Bull. 405* (1939), and *Bull. 522*, 1949.
2. C. E. Millar, *Soil Fertility*, New York, John Wiley & Sons, Inc., 1955, p. 357.
3. T. E. Odland, J. B. Smith, and S. C. Bamon, *Rhode Island Agric. Expt. Sta., Bull. 243*, 1934.
4. E. G. Schafer, L. C. Wheeling, and S. C. Vandecaveye, *Washington Agric. Expt. Sta., Bull. 344*, 1937.
5. L. M. Thomson, *Soil and Soil Fertility*, New York, McGraw-Hill Book Co., 1957, p. 362.
6. C. B. Williams, S. K. Jackson, and F. T. Meacham, *N. Carolina Agric. Expt. Sta., Bull. 256*, 1928.
7. D. Milne, A. Muhammad, and Z. Alam, *Handy Notes for Agriculturists and Horticulturists*, Lahore, Civil and Military Gazette Ltd., 1950, p. 125.
8. W. Roberts and K. Singh, *A Textbook of Punjab Agriculture*, Lahore, Civil and Military Gazette Ltd., 1951, p. 120.
9. A. Walkley and I. A. Black, *Soil Sci.*, 1934, 37, 29.
10. C. S. Piper, *Soil and Plant Analysis*, University of Adelaide Press, 1950, p. 149.
11. A.O.A.C., *Official Methods of Analysis*, Washington, D.C., Association of Official Agricultural Chemists, 1955, p. 11.

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EFFECTS OF DRESSINGS WITH FUNGICIDES AND INSECTICIDES ON AMERICAN COTTON IN THE SUDAN CENTRAL RAINLANDS

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Summary

Fungicidal seed dressings in use elsewhere in the Sudan for the control of blackarm disease (*Xanthomonas malvacearum*) were found to be unnecessary on American cotton grown at the Central Rainlands Research Station of the Sudan, but their use, together with that of seed dressings with insecticides, was found to prevent the normally heavy losses in plant population.

Improvements in yield of about 20 per cent. of the mean were obtained in only one case, where establishment was low, by the use of dieldrin seed dressings, and resulted from increases in the first two pickings.

Soil dressings with insecticides were not found to be advantageous.

In the Sudan Gezira, on Egyptian cotton, fungicidal seed dressings, of which the most efficient were organo-mercurials, were found to be advantageous in controlling seed-borne spread of blackarm disease due to *Xanthomonas malvacearum* [1]. Precautionary trials with various seed dressings were therefore carried out when American cotton was introduced on the newly established Central Rainlands Research Station at Tozi, in the Blue Nile Province of the Sudan.

It was found, however, that the variety of cotton used, BAR 7/8.1, maintained its inbred resistance to the disease, which, moreover, was never seen in conditions which suggested an infection from the seed. At the same time, heavy losses in plant population were observed, up to 60 per cent. of the seed planted failing to form mature plants, and there were indications that these losses were to some extent reduced by the seed dressings.

The pathogens or insects attacking the seeds or seedlings before emergence were not isolated, but most of the post-emergence losses were due to termites and millipedes.

After 1954 it was evident that cotton at Tozi had to be planted at the very first rains; this was also a time when the tractors were required for equally essential early weed-controlling cultivations. It was hoped to reduce the pressure on the machinery by planting the cotton in dry soil before the first rains, and this further increased the need for controlling loss of seed before emergence.

Effect of Seed and Soil Dressings

Experiment 1.

In 1954 nine seed dressings were compared in a field experiment, six

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being fungicides alone, along with BHC used alone or together with each of two fungicides, viz.:

No. (1) An organo-mercurial in common use, giving a rate of dressing of Hg 0·000044 per cent. of the weight of seed.
„ (2) A more concentrated formulation of No. (1), giving 0·0002 per cent. Hg as applied.
„ (3) Another organo-mercurial giving the same rate of Hg as No. (2) but having a different organic radical.
„ (4) Tetramethyl thiuram disulphide (TMTD) applied at 0·0022 per cent.
„ (5) and No. (6) Two specially formulated organic compounds.
„ (7) BHC, applied alone, to give 0·001 per cent. gamma isomer.
„ (8) As No. (7), together with No. (1).
„ (9) As No. (7), together with No. (4).

The experiment was hand-planted at 51,000 seeds per feddan[1] in 32-in. rows, on 31 August 1954.

Table 1 gives the plant populations 8 and 22 days after planting; emergence was slow and not complete before 22 days.

TABLE 1. *Effect of Nine Seed Dressings on Populations of American Cotton Plants*

Fungicide	*Rate of active ingredient %*	*Plant populations (thousands per feddan)*			
		8 days after planting		*22 days after planting*	
		No BHC	*BHC 0·001%*	*No BHC*	*BHC 0·001%*
None	..	13·8	11·0	23·2	29·7
Mercurial 1	0·000044 Hg	15·5	17·9	26·0	37·3
„ 2	0·0002 Hg	19·0	..	30·9	..
„ 3	0·0002 Hg	14·8	..	25·1	..
TMTD	0·001 TMTD	9·8	15·1	22·1	27·8
Organic 1	..	19·8	..	33·6	..
„ 2	..	20·2	..	27·5	..
Comparable means		13·0	14·7	23·4	31·6
Least significant differences	P = 0·05	8·0		7·0	
	P = 0·01	10·9		10·0	

One of the mercurials, one of the organics, and the mercurial/BHC mixture, significantly improved the plant populations at 22 days, by 7,700, 10,400, and 14,100 plants per feddan respectively. The two components of the mercurial/BHC mixture when applied separately did not have any significant effect, although the difference for BHC used alone closely approached significance at P = 0·05.

Such large increases in population might be expected to result in increased yields of cotton, but in fact there was no significant increase.

[1] 1 feddan = 1·038 acres = 5024 sq. yds.; 1 rotl = 0·99 lb.

Comparison with another experiment on the station, investigating the relation between date of planting and plant population [2] explained this. It had not at that time become apparent at Tozi that cotton must be planted very early. The seed-dressing experiment was not planted until 31 August and the above-mentioned experiment showed that, in this year (1954), with planting only as late as 17 August, differences in plant population within the range of 23 to 37 thousand per feddan had no significant effect on yield. The figures are included in Table 5 (p. 131).

Experiment 2.

In the following year (1955) an experiment was planted on 11 June, at the first rains, to compare commercially obtainable seed dusts. The dressings used were:

(1) The organo-mercurial used in Treatment 1 in Experiment 1 applied to give 0·00002 per cent. Hg.
(2) The TMTD dressing used as Treatment 4 in Experiment 1, applied at 0·001 per cent. active ingredient.
(3) and (4) Combinations of Treatments 1 and 2 respectively, with BHC, to give in addition 0·002 per cent. gamma isomer.
(5) BHC alone, at 0·002 per cent.

TABLE 2. *Effect of Five Seed Dressings on Population of American Cotton Plants*

Fungicide	*Rate of active ingredient %*	*Populations, thousands per feddan, 34 days after planting*		
		No BHC	*BHC 0·002%*	*Mean*
None .	..	27·2	31·6	29·3
Mercurial	0·00002 Hg	31·9	30·4	31·2
TMTD .	0·001% TMTD	29·2	33·0	31·1
Mean		29·4	31·7	30·5

Least significant difference (within body of table) { P = 0·05 1·5 ; P = 0·01 2·1

In good climatic conditions, the emergence was rapid and unusually high; 27,000 plants per feddan, or over 70 per cent. of the 40,000 seeds planted, being obtained without any seed dressing. This precluded any striking improvement from seed dressing; nevertheless, as shown in Table 2, all five treatments were effective.

The TMTD/BHC dressing gave the best improvement, of nearly 6,000 plants per feddan, followed by the organo-mercurial alone, with an increase of 4,700. Subsequent losses right through to harvest time were very slight.

None of the treatments, however, was effective in improving the yield, and again reference to the results of the current year's experiment on plant population, for comparable dates of planting (see Table 5, p. 131), shows that no difference in yield was to be expected from population increases of this order.

In the same year the first large-scale dry planting was attempted, two fields of 15 feddans each being planted during the first week of June with seed which had been dressed with an organo-mercurial/BHC mixture ('Mergamma B'), at 8 oz. per cwt. Heavy seed rates—75,000 in one field and 65,000 in the other—were used; emergence was 65,000 and 40,000 plants per feddan respectively, the former being a remarkably successful establishment, and even the latter, with 39 per cent. of non-emergent seed, was much better than usual; Table 3 gives the subsequent losses in population, after emergence, for this latter field: the overall loss of seedlings, nearly 23 per cent., was somewhat higher than usual, due apparently to the high termite activity in this dry year. In

TABLE 3. *Losses in Plant Population, after Emergence, in a Field of Dry-Planted American Cotton*

Days after planting	*Population, thousands per feddan*	*Losses, as % of 27-day level*
27	39·8	..
41	35·7	10·3
53	33·4	5·8
73	32·3	2·8
86	31·1	3·0
99	30·8	0·7
	Total	22·6

Number of seeds planted: 65,000 = 100%
Lost before emergence: 25,000 = 39%
Lost after emergence: 9,000 = 14%

this case, however, the pre-emergence loss was still little more than twice the post-emergence loss (calculated on seed planted); more often the ratio is 4:1. However, the post-emergence loss is by no means negligible, and appears to be due almost entirely to termite and millipede attack on the base of the stem or the root during dry periods.

Great success had been obtained at Tozi in suppressing termite attack on groundnuts by using dieldrin soil dressings (unpublished data). A trial with cotton was therefore planted, in which BHC and dieldrin were applied to the soil, each at 0·5, 1, or 2 r.p.f.[1] active ingredient. There was no difference in percentage emergence between any of the treatments, or from the untreated control, and subsequent attack by termites and millipedes was negligible throughout, as was also the loss in population to harvest time. This, in marked contrast to the damage caused by these pests in the large-scale production fields, suggests that the influence of the insecticides was exerted over a wider area than the plots to which they were applied, repelling the insect pests from the entire experiment.

Experiment 3

By 1956 an interim technique for the growing of American cotton had been adopted, and the use of 'Mergamma B' organo-mercurial/BHC seed dressing at 8 oz. per cwt. was standard, ensuring levels of plant

[1] r.p.f. = rotls/feddan.

Comparison with another experiment on the station, investigating the relation between date of planting and plant population [2] explained this. It had not at that time become apparent at Tozi that cotton must be planted very early. The seed-dressing experiment was not planted until 31 August and the above-mentioned experiment showed that, in this year (1954), with planting only as late as 17 August, differences in plant population within the range of 23 to 37 thousand per feddan had no significant effect on yield. The figures are included in Table 5 (p. 131).

Experiment 2.

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[1] r.p.f. = rotls/feddan.

population satisfactory for the current stage of development. Nothing in the experiments of 1954 and 1955 suggested that other dressings currently available would be better for cotton, but an experiment was planted in 1956 to examine the effects of dieldrin, which was proving so successful in controlling insect pests of groundnuts on the station.

Dieldrin as a seed dressing at 1/500 w/w active ingredient, and as a soil dressing at 1 r.p.f. active ingredient, were tested, separately and together, with an untreated control. A foliar spray treatment with DDT at 1 r.p.f. active ingredient was also included in the experiment, as this had sometimes been advantageous in previous years; in this experiment it had no effect, and it is not referred to in the discussion below.

The experiment was planted rather later than usual, on 26 June, since this was the date of the first rains. Subsequently the season was marked by very heavy rains and serious flooding. No fungicidal seed dressing was applied, and this, with the very wet soil conditions immediately following planting, probably accounts for the very low emergence rate.

Part I of Table 4 shows that, out of some 28,000 seeds per feddan planted, about 13,000 seedlings, or less than 50 per cent., emerged in the first 5 weeks. The dieldrin seed dressing improved the plant population by 4,000 per feddan over the untreated plots, or nearly 30 per cent. of the experiment mean, whilst the soil dressing gave a mean increase of 1,500 per feddan, both differences being significant at $P = 0{\cdot}01$. Part II of the table gives the plant population at the time of the first picking (5 November). The mean loss of plants in the experiment over the 13 weeks between the date of the emergence counts (8 August) and the date of the first picking was only 810 per feddan, or little over 6 per cent. of the mean population on 8 August. This low rate of loss is explained by the almost complete absence of termite activity on the very wet and often flooded soil. This loss, slight though it was, was however reduced by the soil dressings; the mean loss with the soil dressing was only 320 plants per feddan, compared with 1,310 plants lost where no soil dressing was given. The mean loss for the treatments containing seed dressing was 545 per feddan compared with 1,080 for those without. It is likely that, had the termite attack been more normal, the soil dressings would have shown more effect throughout the experiment.

The enhanced populations, however, were not directly reflected in increased total yields. Four pickings were made over a 6-week period from 5 November to 15 December, and in the total yields, shown in Part III of Table 4, the only improvement which is statistically significant was that obtained with the seed dressing, where a mean increase of 120 r.p.f. seed cotton was obtained. The mean yield with seed dressings (558 r.p.f.) was extremely good in view of the very adverse season and low plant population.

In spite of its having improved the population, the soil dressing in the absence of seed dressing appeared to reduce yield, an anomalous result, for which no explanation is offered.

Part IV of Table 4 gives the yields broken down into their component pickings. It is at once apparent that the effect of seed dressing lies in the early pickings. The mean first picking, for the treatment with seed

dressings, was 164·7 r.p.f. seed cotton, compared with only 83·2 where no seed dressing was given. In the second picking, a week later, the mean yield from seed-dressed plots was 171·5 r.p.f., still much higher than that from the untreated plots (118·7). The highest overall yield came from the third picking, 2 weeks later: the mean for the seed-dressed plots remained much the same, at 165·4 r.p.f., but that of the untreated plots had risen to 167·3. In the fourth and last picking, returns were

TABLE 4. *Effect of Dieldrin Seed and Soil Dressings on Yield and Plant Population of American Cotton*

PART I. • *Population on 8 August, 5 weeks after sowing. In thousands per feddan. Mean of twelve replications*

Seed dressing	*Soil dressing*		*Mean*
	None	*1 r.p.f.*	
None	10·02[a]	11·79[a]	10·90[b]
1/500 w/w	14·32[a]	15·57[a]	14·95[b]
Mean	12·17[b]	13·68[b]	12·93

		a	*b*
Least significant differences:	P = 0·05	1·46	1·02
	P = 0·01	1·96	1·38

PART II. *Harvest Population, and losses between 8 August and 5 November. In thousands per feddan*

Treatment	*Harvest population (5 Nov.)*		*Loss since 8 Aug.*
No seed dressing			
No soil dressing			
No DDT spray	8·40	8·24	1·78
With DDT spray	8·08		
With soil dressing			
No DDT spray	11·84	11·41	0·38
With DDT spray	10·98		
With seed dressing			
No soil dressing			
No DDT spray	13·50	13·68	0·84
With DDT spray	13·86		
With soil dressing			
No DDT spray	15·60	15·32	0·25
With DDT spray	15·04		
Mean	12·10	12·10	0·81
Means of:			
No soil dressing			1·31
Soil dressings			0·32
No seed dressings			1·08
Seed dressings			0·55

Least significant differences	P = 0·05	1·67	–
	P = 0·01	2·23	–

Table 4 (*contd.*)

PART III. *Total Yield of Seed Cotton. In r.p.f.*

Dieldrin treatments	*Foliar sprays of DDT*		*Mean*
	None	*1 r.p.f.*	
No seed dressing			
(i) No soil dressing	457·9[a]	544·0[a]	500·9[b]
(ii) With soil dressing	371·3[a]	375·8[a]	373·6[b]
Seed dressed, 1/500 w/w			
(i) No soil dressing	532·3[a]	559·0[a]	545·7[b]
(ii) With soil dressing	586·2[a]	555·4[a]	570·8[b]
Means:			
of no seed dressings	414·6[b]	459·9[b]	437·2[b]
of seed dressings	559·3[b]	557·2[b]	558·3[b]
of no soil dressings	495·1[b]	551·5[b]	523·3[b]
of soil dressings	478·7[b]	465·6[b]	472·1[b]
of all dieldrin dressings	486·3[c]	508·6[c]	..
	Experiment mean yield		497·7

		a	*b*	*c*
Least significant differences:	P = 0·05	127·7	90·2	63·8
	P = 0·01	170·5	120·5	85·2

PART IV. *Harvests at each picking, and yield per plant*

Treatments	*Yield, r.p.f., seed cotton*					*Rotls per plant*
	1st picking	*2nd picking*	*3rd picking*	*Last picking*	*Total*	
No seed dressing						
No soil dressing						
No DDT spray	81·2	125·8	176·6	74·3	457·9	0·054
With DDT spray	89·0	142·0	222·2	90·8	544·3	0·067
With soil dressing						
No DDT spray	73·2	94·0	144·8	59·3	371·3	0·032
With DDT spray	89·4	113·0	125·6	47·8	375·8	0·034
With seed dressing						
No soil dressing						
No DDT spray	152·8	169·6	162·4	47·5	532·4	0·039
With DDT spray	161·2	180·6	156·0	57·2	559·0	0·039
With soil dressing						
No DDT spray	170·4	170·8	181·2	63·8	586·2	0·038
With DDT spray	174·2	165·0	162·0	54·2	555·4	0·037
Means:						
without seed dressing	83·2	118·7	167·3	68·0	437·2	0·047
with seed dressing	164·7	171·5	165·4	55·7	558·3	0·038
Overall mean	123·9	145·1	166·4	61·9	497·7	0·043
Least significant differences (within each column) P = 0·05	39·1	46·9	76·1	31·8	127·7	
Least significant differences (within each column) P = 0·01	52·2	62·7	102·5	42·5	170·5	

low, but the yield for the plots without seed dressing, 68 r.p.f., was higher than that of the treated plots, at 55·7.

This acceleration of maturity of the crop by seed dressing is hard to explain. In 1953 it was recorded at Tozi that increasing plant population accelerated the maturity of the crop, although without increasing the yield [3]. In 1954 sorghum grown from seed which had been dressed with the related insecticide aldrin, flowered 14 days before plants from untreated seed (unpublished data).

TABLE 5. *The Relation of Plant Population and Yield of American Cotton, in Four Seasons*

(*Extracts from Annual Reports of Central Rainlands Research Station, Tozi*)

Year	Date planted	Yields of seed cotton, in r.p.f. at different population ranges (thousands per feddan)					
		4–10	10–20	20–30	30–40	40–50	Over 50
1953	19 July	*931	*1,291	1,359	..	..	..
1954	9 July	..	910	1,026	1,335	..	1,504
1954	17 Aug.	418	318	370	..	392	..
1955	23 June	1,070	1,699	1,255	..	..	1,863
1956	10 July	..	609	590	660	..	723
1956	21 July	..	300	465	386	..	306

* Mean of two yields.

Reduction of the total yield by the soil dressing in the absence of seed dressing is also clarified by the separation into four pickings. In the first picking there was no real difference, but the great increases in yield from the control plots in the second and third pickings were not paralleled by the plots with soil dressings alone, and the trend was sustained into the last picking.

The last column of Part IV of Table 4 shows the yield of seed cotton per plant. The mean figure for control plots was 0·061 rotls per plant, very nearly double that for plots with soil dressing only (0·033) and still well above the mean for plots with seed dressing (0·039). This difference is not directly related to the plant population, so that it does not appear to be the result of competition for some nutrient in short supply. Again, there is insufficient information to explain the effect.

Discussion and Conclusions

The optimum plant population for American cotton at Tozi is still undecided, since it apparently varies with date of planting, the place of cotton in the rotation, and the wetness of the season. It appears to lie above 20,000 plants per feddan in all seasons, and probably over 30,000 in most; there is some suggestion that very high yields obtained with populations around 70,000 per feddan result in decreased quality [4]. Table 5 gives a summary of the results for the relation of plant population to yield, for different planting dates in different years; they are extracted from the Annual Reports of the Central Rainlands Research

Station, Agronomy Section. Lack of firm agronomic data for comparison hampers the interpretation of the results of seed dressing.

It appears that fungicide/insecticide seed dressings improved establishment in all cases. In two of the three experiments, no economic return resulted. Here, the plant populations obtained with the various treatments were all above the optimum level for the conditions (date of planting or type of season) as inferred from Table 5. In the one case where the populations were below the optimal range (taken as above 20,000 plants per feddan), improvement of the populations by seed dressing, in this case dieldrin, resulted in increased yields.

It therefore seems that, until further evidence accumulates, a seed dressing of a fungicide, preferably an organo-mercurial, together with an insecticide, preferably dieldrin, should be used as an insurance against very poor yields resulting from low plant populations in adverse circumstances.

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REFERENCES

1. S. A. J. Tarr, *Empire Cotton Growing Rev.*, 1933, **30**, 1.
2. Sudan Ministry of Agriculture, *Ann. Rep. Centr. Rainlands Res. Sta.*, 1954, Section 4.
3. —— ibid., 1953, Section 4.
4. —— ibid., 1955, Section 4.

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SOME FACTORS AFFECTING LAMB MORTALITY IN RAHMANI SHEEP

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Summary

The records of 1,109 Rahmani lambs were studied to determine the relation of year, season of lambing, sex, type of birth, birth weight, and age of dam, to lamb mortality at birth and at 4 months of age.

The average percentage of lamb mortality at birth was 7·7, and at 4 months of age it was 20·8. Differences from year to year in mortality rate at birth and at 4 months of age were statistically highly significant. Winter-born lambs had higher mortality rates than summer-born lambs, but not significantly so. Rams and twins had higher mortality rates than ewes and singles respectively, but again the differences were not significant. There was a significant decrease in mortality rate with increase of birth weight, up to 4·4 kg. Age of dam did not have a significant effect on lamb mortality, though there was a decrease with age, up to 5 years.

THE number of lambs weaned in a flock is determined by the lambing percentage and mortality rate. Therefore, knowledge of the factors affecting the survival of lambs from birth up to weaning age can help in making sheep-raising more profitable and successful. The effect of some of these factors on lamb mortality at birth and at 4 months of age was studied in the present investigation.

The Data

The data used in this study refer to 1,109 Rahmani lambs from 895 lambings, at the Experimental Farm of the College of Agriculture, from 1943 to 1955. Lambing took place all the year round, but most of the lambs were born during the months from September to February. These are referred to as winter-born lambs. The rest were born during the months from March to August (summer-born lambs). The system of management used in the flock was described in an earlier paper [1].

Only records of lambs carried to full term were used. The total number of dead lambs was 298, including lambs dead at birth and lambs which died from birth to 4 months of age. The records were analysed to determine the relation of year, season of lambing, sex, type of birth, birth weight, and age of dam, to lamb mortality at birth and at 4 months of age.

Results and Discussion

The average percentage of Rahmani lamb mortality at birth and at 4 months of age was 7·7 and 20·8, respectively, making a total lamb mortality of 26·9 per cent. Chapman and Lush [2] reported 5 per cent. of stillborn lambs in a flock of high-grade Hampshires. Venkatachalam *et al.* [3] found, in a flock of six breeds of sheep, 2·3 per cent. of stillborn lambs, and a mortality up to 2 months of age of 28·6 per cent.; stillbirths

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were largely lambs that died because of difficulty at parturition. In the Rambouillet sheep, Terrill [4] reported that stillborn lambs were 7·4 per cent. and that the mortality rate at weaning was about 18·9 per cent. Among Rahmani and Ossimi lambs in the Cairo University flock, mortality rate at 4 months of age was 9·3 and 11·5 per cent. respectively [5.]

Year

The percentages of lamb mortality, at birth and at 4 months of age, for the years 1943–55 are given in Table 1. At birth they ranged from 2·6 to 14·5, and at 4 months from 7·9 to 47·4. Differences from year to year, at both ages, were statistically highly significant. Such

TABLE 1. *Lamb Mortality in the Years 1943–55*

Year of birth	No. of lambs born	At birth		No. of lambs born alive	From birth to 4 months	
		No. of dead lambs	% mortality		No. of dead lambs	% mortality
1943	62	9	14·5	53	20	37·7
1944	93	7	7·5	86	12	14·0
1945	93	5	5·4	88	16	18·2
1946	75	3	4·0	72	12	16·7
1947	56	2	3·6	54	9	16·7
1948	39	1	2·6	38	18	47·4
1949	57	2	3·5	55	12	21·8
1950	68	8	11·8	60	6	10·0
1951	91	13	14·3	78	8	10·3
1952	111	10	9·0	101	8	7·9
1953	133	6	4·5	127	34	26·8
1954	84	7	8·3	77	8	10·4
1955	77	6	7·8	71	6	8·5

differences are usually associated with feeding and health conditions of the flock, and with weather conditions from year to year. Ragab *et al.* [5], studying another flock of Rahmani and Ossimi sheep, came to the same conclusion.

Season of Lambing

The mean mortality rate among summer-born lambs was 7·6 per cent. at birth and 16·5 per cent. at 4 months of age. Among winter-born lambs the corresponding rates were 7·7 and 23·3 per cent. (Table 2). Although the summer-born lambs had lower mortality rate at 4 months of age, the differences were not statistically significant.

Most of the summer-born lambs were born in March, April, and May [1]. Most of the ewes grazed on berseem (available from November until May) throughout their gestation period. This helped to bring them into good condition at lambing time and during at least the first part of the lactation period. Most of the winter-born lambs were born in October, November, and December [1]; the condition of the ewes was not so good as that of those which lambed in the summer. It took them some time to improve their condition and build up some reserves, during

which the lambs were probably suffering from lack of enough milk and possibly from unfavourable weather and housing conditions. Asker and El-Itriby [6], studying calf mortality in Egyptian buffaloes, found that the heaviest losses were during the months November, December, January, and February.

TABLE 2. *Relation of Season to Lamb Mortality*

Summer				*Winter*			
Month of lambing	*Number born*	*% mortality*		*Month of lambing*	*Number born*	*% mortality*	
		At birth	*Birth to 4 months*			*At birth*	*Birth to 4 months*
Mar.	123	11·4	8·3	Sept.	23	4·5	19·0
Apr.	85	8·2	19·2	Oct.	113	9·7	21·6
May	113	2·7	24·5	Nov.	282	4·2	21·8
June	72	8·3	15·2	Dec.	208	9·6	22·3
July	9	11·1	12·5	Jan.	60	6·7	32·1
Aug.	4	0·0	0·0	Feb.	17	35·3	54·5
Total or mean	406	7·6	16·5	Total or mean	703	7·7	23·3

Sex and type of birth

Table 3 shows the average mortality rates for rams and ewes, singles and twins, at birth and from birth up to 4 months of age. Differences between the four types were not statistically significant at birth, but were significant at 4 months of age. Ram lambs had higher mortality rates than ewe lambs, and twins higher than singles.

TABLE 3. *Relation of Sex and Type of Birth to Lamb Mortality*

Sex and type of birth	*No. of lambs born*	*At birth*		*No. of lambs born alive*	*Birth to 4 months*		*% total mortality*
		No. of dead lambs	*% mortality*		*No. of dead lambs*	*% mortality*	
Ram singles	342	29	8·5	313	73	23·3	29·8
Ram twins	193	19	9·8	174	49	28·2	35·2
Ewe singles	393	20	5·1	373	43	11·5	16·0
Ewe twins	181	17	9·4	164	48	29·3	35·9
Total or mean	1,109	85	7·7	1,024	213	20·8	26·9

Phillips and Dawson [7] reported that sex and type of birth had no significant effect on the survival of lambs up to 3 months of age. Venkatachalam *et al.* [3] found that mortality rate among twin and ram lambs was significantly higher than among single and ewe lambs, respectively, at 2 months of age. Terrill [4] found a mortality rate at birth of 9·3 per cent. for single lambs and 4·3 per cent. for twins; up to weaning it was 9·7 and 19·7 per cent. respectively: more twins than singles died between birth and weaning. In Ossimi lambs the mortality rate was higher among males than females at 4 months of age [5]. No significant differences were found between singles and twins among either the

Ossimi or the Rahmani lambs. Asker and El-Itriby [6] found that mortality rate was significantly higher among male calves than among females.

The average total mortality of 26 per cent. and, among twin lambs, of over 35 per cent., is very high, and increases the chances of losing desirable genes, in addition to its effect on net income.

The differential mortality between male and female lambs could have been caused by sex-linked or sex-limited genes.

Birth weight

For studying the effect of birth weight on lamb mortality, 521 lambs were available with an average birth weight of $3{\cdot}0 \pm 0{\cdot}81$ kg. Of these lambs, 45 died at birth and 84 died between birth and 4 months of age; their average birth weights were $2{\cdot}5 \pm 0{\cdot}91$ and $2{\cdot}9 \pm 0{\cdot}61$ kg., respectively. Table 4 shows all birth weights classified into groups with equal

TABLE 4. *Effect of Birth Weight on Lamb Mortality*

Birth weight (kg.)	*0·5 to 0·9*	*1·0 to 1·4*	*1·5 to 1·9*	*2·0 to 2·4*	*2·5 to 2·9*	*3·0 to 3·4*	*3·5 to 3·9*	*4·0 to 4·4*	*4·5 to 4·9*	*5·0 to 5·4*	*5·5 to 5·9*
Total no. of births	1	4	28	71	129	122	83	62	16	4	1
No. of dead lambs	1	4	10	23	36	27	16	7	3	1	1
% mortality	100·0	100·0	36	32	27	22	19	11	19	25	100
No. dead at birth	1	4	7	7	9	12	3	0	1	0	1
% mortality	100·0	100·0	25	9	7	10	4	0	6	0	100
No. dead between birth and 4 months	0	0	3	16	27	15	13	7	2	1	0
% mortality	..	..	11	23	21	12	16	11	13	25	..

intervals, from 0·5 up to 5·9 kg. The total mortality rate decreased significantly with the increase of birth weight, up to 4·4 kg. Phillips and Dawson [7], Venkatachalam *et al.* [3], and Ragab *et al.* [5] all found similarly a significantly higher mortality for lambs with lighter birth weights.

Regan *et al.* [8], studying calf mortality, found that surviving Jersey calves tended to have a slightly though not significantly higher mean birth weight than those that died. He also found that the calves towards both extremes in weight, either light or heavy, manifested the greater mortality. Consequently, the variance of the group that died was greater than that of the group that lived. This point is also illustrated in Table 4 and is in agreement with data reported by Venkatachalam *et al.* [3] and Ragab *et al.* [5].

Selection should favour lambs with heavy birth weights in order to reduce mortality rate among their offspring. This does not usually take place until weaning, and weight at that time is an important factor in determining which lambs should be kept in the flock. Fortunately birth weight is correlated with weaning weight [9, 10], so that selection for weight will automatically improve birth weight proportionately with the genetic correlation between the two characters, and the heritability of birth weight.

Age of Dam

Table 5 shows the effect of age of dam on lamb mortality at birth. Dams were classified into ewes having singles and ewes having twins. In both groups there was a decrease in mortality rate with the advance of age up to 5 years, after which it started to increase, but the differences were not statistically significant. Terrill [4] found that lamb mortality at birth and at weaning decreased with the increase of dams' age up to 6 and 4 years respectively.

TABLE 5. *Relation of Age of Dam to Lamb Mortality at Birth*

Age in years	*Ewes having twins*		*Ewes having singles*		*All ewes*
	Ewe yrs.	% *mortality*	*Ewe yrs.*	% *mortality*	% *mortality*
2	32	10·9	247	7·3	8·0
3	56	8·9	151	6·6	7·6
4	53	8·5	99	5·1	6·8
5	43	8·1	63	3·2	6·0
6	24	10·4	44	6·8	8·7
7	17	14·7	20	10·0	13·0
Total or mean	225	9·6	624	6·4	7·7

Young ewes with lambs need more care in feeding and management than mature ewes. Ewes which are 6 years of age or older should be carefully selected on their lamb records, since mortality tends to be higher among their lambs; they are also less productive [1]. This will tend to shorten the generation interval and will be accompanied by genetic improvement if the selected replacements are superior in the desired characteristics.

REFERENCES

1. H. A. KARAM, *J. Anim. Sci.*, 1957, **16**, 990.
2. A. B. CHAPMAN and J. L. LUSH, *J. Hered.*, 1932, **23**, 473.
3. G. VENKATACHALAM, R. H. NELSON, F. THORP, JUN., R. W. LUECKE, and M. L. GRAY, *J. Anim. Sci.*, 1949, **8**, 392.
4. C. E. TERRILL, Mimeographed report. Western Sheep Breeding Laboratory, Dubois, Idaho, 1952.
5. M. T. RAGAB, A. A. ASKER, and M. R. KADI, *Indian J. Vet. Sci. Anim. Husb.*, 1954, **24**, 89.
6. A. A. ASKER and A. A. EL-ITRIBY, *Empire J. Expt. Agric.*, 1957, **25**, 151.
7. R. W. PHILLIPS and W. M. DAWSON, *U.S.D.A. Circular No. 538*, 1940.
8. W. M. REGAN, S. W. MEAD, and P. W. GREGORY, *Growth*, 1947, **11**, 101.
9. F. N. BONSMA, *Univ. Pretoria Publications*, 1939, Series I; Agric. No. 48, 214 pp.
10. G. R. KEEN and W. L. HENNING, *J. Anim. Sci.*, 1949, **8**, 362.

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THE EFFECT OF SPACING ON THE ENVIRONMENT AND PERFORMANCE OF CACAO UNDER NIGERIAN CONDITIONS

II. ECOLOGICAL FACTORS (SOIL MOISTURE, SOIL NITRATES, SHADE, AND MICRO-CLIMATIC CONDITIONS)

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Summary

A comparative study of cacao at different stand densities, and secondary forest, has been made with special reference to soil moisture, soil nitrates, shade and micro-climatic conditions.

The level of soil organic matter and plant nutrients was higher, and the physical condition of the soil better, under the forest than under cacao.

A high positive correlation was found between stand density and soil moisture, soil nitrates, organic litter, soil nutrient status, and the yield of cocoa.

The pattern of soil nitrate fluctuation under forest growth and under cacao at various stand densities, in relation to seasons, was quite different from that usually occurring under exposed soil conditions. The level of soil nitrates throughout the season was positively correlated with stand density.

It is generally accepted that the commonly high apparent fertility of soils under tropical forest is a result of accumulation of plant nutrients in a closed cycle of 'growth–decay–reabsorption'. This is undoubtedly true for forest soils in Nigeria, where nutrient reserves in decomposing rocks are within the reach of tree roots. Most Nigerian cacao grows on such potentially fertile soils.

There are a number of questions which arise when a change from forest to cacao plantation takes place, notably these:

What is the soil-nutrient level under cacao monoculture and how does it differ from that under the original forest? In particular, to what extent are the soil-nitrate and soil-moisture levels affected? (Nitrates are thought to be of special importance in Nigeria [1].)

Second, how is the level of soil nutrients, of soil organic matter, and of shade affected by the density of stand? To what extent is the increase of the crop with increased density of stand a result of differences in the level of soil nutrients?

Finally, is there any evidence that, under established cacao, a steady deterioration in the level of nutrients and soil organic matter occurs progressively over a period of years?

A knowledge and understanding of such changes and balances is essential for devising a system of management which will secure the highest efficiency of production.

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Experimental

Measurements of soil moisture and soil nitrates under various cacao spacings and forest cover have been made, together with organic litter, other soil nutrients, light intensity, and micro-climatic conditions.

The experiment was superimposed on the 7×7 Latin Square Cacao Spacing Trial described in Part I of this series [2], with certain modifications in treatments.

The investigation was complicated by the presence of emergent shade trees (Gliricidia) on some of the wider spacings, and also by sporadic capsid damage. This damage has resulted in the development of grass and herbaceous plants as a ground flora in irregular patches on the widest spacings (10×10, 12×12, and 15×15 ft.). The close-spaced plots are completely devoid of ground vegetation, the soil surface being covered with thick leaf-litter. The presence of weedy patches and Gliricidia may be expected to affect the soil nitrate content; it was decided to exclude the 10×10- and 12×12-ft. treatments from the present investigation. Instead, a sixth treatment was introduced in the form of secondary forest in order to compare a cacao plantation with forest conditions; a strip of secondary forest adjoining the 7×7 spacing trial was divided into seven plots of the same size as those in the spacing trial.

For convenience the experiment was divided into two parts, with sixfold replication:

A. Nitrate fluctuations under three cacao spacings:
   1. 5×5 ft.
   2. 6×6 ft.
   3. 7½×7½ ft.

B. Nitrate fluctuations under three types of cover:
   4. Closed-canopy cacao, 6×7½-ft. spacing.
   5. Wide-spaced cacao, 15×15-ft. spacing.
   6. Forest growth.

All the main plots were split for two subtreatments: with and without nitrogenous fertilizers; ammonium sulphate was broadcast uniformly over the sub-plots concerned at the rate of 3 cwt. per acre, on 23 April 1955. The total number of treatments under investigation is therefore twelve: six cacao spacing and cover types, each with and without nitrogenous fertilizer.

Sampling

Soil sampling for nitrate and moisture determination was at intervals of 16 days, but with an 8-day difference between the sampling dates for Parts A and B. This arrangement made it possible to follow changes in soil nitrates under cacao at 8-day intervals.

Sampling was at three depths: 0 to 4 and 4 to 9 in. by means of 2-in. sampling tubes, and 18 to 24 in. by a 1-in. screw auger. Samples from 9 to 18 in. were discarded.

Thirty borings (five borings per sub-plot × six replicates) from each depth formed one composite sample. Thirty-six composites were collected (six main treatments × three depths × two subtreatments), in which nitrate and moisture were determined within 4 hours of sampling. The well-developed, fairly compact soil profiles permitted more accurate sampling near the surface than is usual with loose soils found on cultivated land.

The coefficient of variation for the nitrate values, estimated every 32 days on individual plots in rotation, was usually between 13 and 18 per cent. For the soil-moisture values the coefficient of variation was fairly constant, averaging about 4 per cent.

A sampling plan was devised in the form of a grid, with sets of sampling points defined beforehand by random selection: each sub-plot was divided into five sampling lanes, each 5 ft. wide and 60 ft. long, and at each sampling one soil sample was taken in each lane, at specified points according to a table of random numbers.

Methods of Analysis

Analyses were made by the following methods:

pH: Colorimetric, using $BaSO_4$ as clarifying agent (Kuhn).

Base exchange capacity: Determination of exchangeable hydrogen with CaO-para-nitrophenol buffer after leaching with N/2 acetic acid (Schofield).

Total exchangeable bases: Exchangeable hydrogen determined by CaO-para-nitrophenol method and subtracted from base-exchange capacity.

Carbon: Oxidation with normal dichromate solution and back-titration (Walkley and Black).

Nitrogen: Kjeldahl.

Nitrates: Determined on fresh samples by the conventional colorimetric phenol-disulphonic-acid method.

Moisture: Drying at 105° C.

Results

Soil Nitrate

General curve. The fluctuation of soil nitrates under the exposed conditions of cultivated soil in Nigeria has been studied in detail by Wright [3], Diamond and Hartley [4], Diamond [5], Vine [1], and Kowal [6]. The general shape of the soil-nitrate curve in relation to season was verified by all investigators and its features have been well established.

That curve is characterized by four well-defined periods:

1. low nitrate content during the dry season;
2. rapid increase reaching a maximum, with the onset of the rains;
3. a very low level during the heaviest rains;
4. a further accumulation with the beginning of the rains after the 'little dry season' (September), which, however, does not always occur.

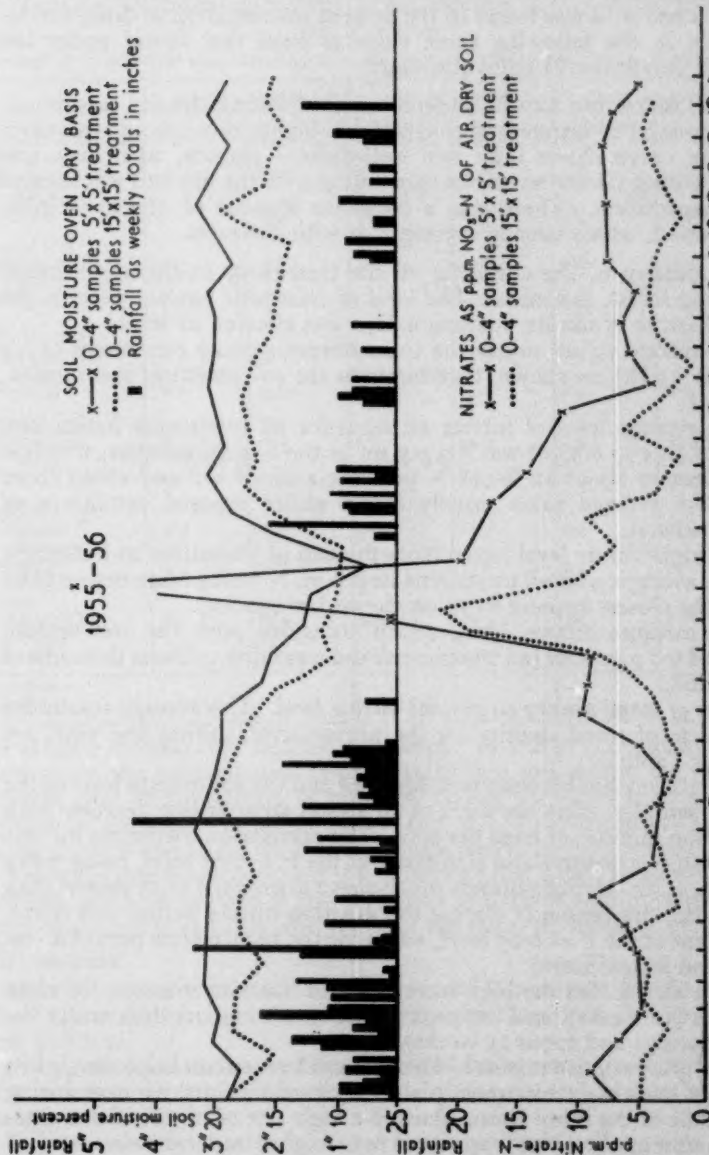
SOIL MOISTURE OVEN DRY BASIS
x—x 0-4" samples 5'x 5' treatment
..... 0-4" samples 15'x15' treatment
Rainfall as weekly totals in inches
1955-56
NITRATES AS ppm. NO3-N OF AIR DRY SOIL
x—x 0-4" samples 5'x 5' treatment
..... 0-4" samples 15'x15' treatment
Rainfall
Soil moisture percent
p.p.m. Nitrate-N
Rainfall
Sampling dates
28.4
14.5
30.5
15.6
1.7
17.7
20.8
18.8
3.9
19.9
5.10
21.10
6.11
22.11
8.12
24.12
9.1
15.1
10.2
26.2
13.3
21.3
29.3
6.4
14.4
22.4
30.4
8.5
16.5
24.5
1.6
9.6
18.6
27.6
4.7

FIG. 1

The fluctuation of soil nitrates under sheltered conditions of cacao and of forest soils was found in the present investigation to differ fundamentally in the following three respects from that found under the exposed conditions of cultivated soil:

1. the maximum nitrate content occurred during the dry season;
2. the level of nitrate was considerably higher throughout the year;
3. the curve shows only two well-defined periods, with high and medium nitrate levels, corresponding with the dry and wet seasons respectively. There was a complete absence of the low-nitrate period, which usually corresponds with the rains.

The pattern of the curve for all the treatments in this experiment, including forest, is similar. The kind of treatment has not affected the general curve of nitrate fluctuation, but has affected its level.

The nitrate values under the two extreme spacing treatments (5 × 5 and 15 × 15 ft.) are shown, together with the soil moisture and rainfall, in Fig. 1.

The average level of nitrate nitrogen for all treatments during one year (28.4.55 to 8.5.56) was 8·7 p.p.m. in the 0–4-in. samples, which is equivalent to about 12 lb. of N per acre/4 in. of soil and about three times the average value usually found under exposed conditions of cultivated soil.

The high-nitrate level lasted from the end of December to February/March, averaging for all treatments 20 p.p.m. N with peaks ranging from 50 on the closest spacing to 22 on the widest spacing.

The medium-nitrate level, which coincided with the wet season, averaged 6·8 p.p.m. N (all treatments) and was fairly uniform throughout the period.

Effect of stand density on the soil-nitrate level. The average results for the effects of stand density on the nitrate level, during one year, are given in Table 1.

The relationship between tree densities and the soil-nitrate level in the 0–4-in. samples, takes the form of an almost straight-line decrease with decreasing number of trees per acre. The correlation coefficient for this relationship is positive and significant at the $P = 0{\cdot}05$ level, being 0·834 ($n = 5$). This relationship was much closer during the rainy season than during the dry season (r during the medium-nitrate period was 0·774, significant at the $P = 0{\cdot}05$ level, while for the high-nitrate period it was small and insignificant).

Fig. 1 shows that the high-nitrate period was longer under the close spacings (10 weeks) (and the peak values much higher) than under the wide spacings and forest (5 weeks).

Effect of ammonium sulphate. Dressings of ammonium sulphate applied to half of each main treatment plot at the rate of 2 cwt. per acre during the middle of the rainy season showed a high rate of nitrification immediately after application; it appeared to be higher under the close-spaced than under the wide-spaced plots, although this relation was not so clear for the intermediate spacings.

The increased nitrate level on plots which received nitrogen persisted

TABLE 1. *Relationship between Stand Density, Soil Nitrates, and Soil Moisture*

(Average of 27 values for each sampling at 16-day intervals, for one year, in p.p.m. nitrate N)

Stand density (trees per acre)	*0–4-in. samples*		*4–9-in. samples*		*18–24-in. samples*	
	Nitrates	*Moisture*	*Nitrates*	*Moisture*	*Nitrates*	*Moisture*
1020 (5×5)						
Without N	10·3	18·6	6·0	14·7	3·2	13·6
Mean	11·1		6·1		3·4	
With N	11·9	18·6	6·1	14·7	3·7	13·6
795 (6×6)						
Without N	10·3	17·8	4·7	13·9	2·8	12·2
Mean	10·1		4·9		2·9	
With N	9·8	17·8	5·2	13·9	3·0	12·2
683 (6×7½)						
Without N	6·5	15·9	3·6	13·4	2·5	12·1
Mean	7·5		4·7		2·6	
With N	8·4	15·9	3·8	13·4	2·9	12·1
577 (7½×7½)						
Without N	8·7	17·5	4·4	14·3	3·4	12·9
Mean	9·7		4·6		3·1	
With N	10·6	17·5	4·9	14·3	2·9	12·9
154 (15×15)						
Without N	5·9	15·3	3·9	13·6	2·4	11·0
Mean	6·7		4·1		2·6	
With N	7·4	15·3	4·3	13·6	2·7	11·0
Forest						
Without N	6·7	13·5	4·5	11·2	3·4	11·6
Mean	7·5		5·1		3·7	
With N	8·3	13·5	5·8	11·2	3·9	11·6
Correlation coefficient	+0·942		+0·748		+0·104	

for about 2 months and then fell to normal. This is in contrast to what happens in the exposed conditions of cultivated soil, where the rise in nitrates after an application of nitrogen, during the *rainy* season, is of very short duration. It would appear that the nitrifying ability of soil under cacao is good, and the loss of nitrates due to leaching small if any.

From the practical standpoint it is of interest that 2 cwt. of ammonium sulphate per acre, applied at the beginning of the wet season, raised the level of soil nitrates, during the period of the rains, by about 35 per cent.

Soil moisture

General curve and level. The soil moisture data in relation to type of cover and cacao spacings are shown along with the nitrate data in Fig. 1 and Table 1.

The level of soil moisture under cacao and forest was high, irrespective of treatments, averaging 16·4 per cent. in the 0–4-in. samples during one year.

It is noteworthy that the values for soil moisture under cacao were remarkably constant during the wet season, varying only slightly with rainfall. This implies that during the wet season the soil was nearly at its field capacity. There was, however, no evidence that a large amount

of leaching occurs during this period. Indeed, the falling gradient of soil moisture with depth, which persisted throughout the year, discounts this possibility.

During the dry season there was a considerable but gradual drop in the percentage of soil moisture, which rose again only gradually to its typical level with the advance of the rains.

The soil moisture contents of the 0–4-in. samples, for all treatments, during the wet season, which corresponded with the lower nitrate level, averaged 17·4 per cent., while those for the samples with the higher nitrate level averaged 10·0 per cent., for approximately 3 months, corresponding roughly with the dry season; the lowest values (5·3) were recorded during mid-February. The level and fluctuations of soil moisture under cacao or forest were thus distinctly different from those usually found under the exposed conditions of cultivated soil, where the level of moisture is much lower, especially during the dry season, when they can drop as low as 2 per cent., and seldom exceed 12 per cent. for any length of time during the wet season. The day-to-day fluctuations under exposed soil conditions are much more pronounced and high values comparable to those here found under cacao during the wet season are seldom obtained.

Perhaps the most striking difference between sheltered and exposed soil conditions is the gradual decline of soil moisture content with depth, under cacao or forest, irrespective of season and treatment, whereas under cultivated soil conditions, the soil moisture content increases with depth, especially at the end of the rainy season and the beginning of the dry season. In this connexion it is of interest that Hardy [7] found that the clear-felling of forest in Trinidad reduced the moisture content of the top-soil by two-thirds during the dry season, and increased the evaporating capacity of the air by 4½ times, and the degree of insolation by 12 times.

Effect of stand density on soil moisture. The soil moisture content was positively correlated with the tree density. The correlation coefficients between the number of cacao trees per acre and percentage of soil moisture, for the 0–4, 4–9, and 18–24-in. samples are +0·989, +0·953, and +0·938, respectively. The soil moisture under forest roughly corresponded with that under 6 × 7½-ft. cacao spacing.

Relationship between Soil Moisture and Nitrates

It has been noted above that the period of high-level nitrate accumulation under forest or cacao corresponds with the dry season, during which period the soil moisture content gradually drops and that of nitrate rises.

Statistical examination of the soil moisture and nitrate data shows a consistent and similar negative correlation under all spacing treatments (see Table 2). The cacao stand density thus had no apparent influence on this relationship.

A similar negative correlation exists between rainfall and the surface (0–4 in.) nitrate values, with correlation coefficients varying from −0·54 to −0·78. Explanation of this negative relationship is not easy, especially

TABLE 2. *Correlation Coefficients between Soil Moisture and Nitrates, in relation to Spacing, during One Year* (n = 27)

	Depth, in.		
Spacing, ft.	*0–4*	*4–9*	*18–24*
5×5	−0·535	−0·451	−0·404
6×6	−0·528	−0·528	−0·448
6×7½	−0·540	−0·367	−0·456
7½×7½	−0·590	−0·358	−0·187
15×15	−0·582	−0·450	−0·340
Forest	−0·140	−0·280	−0·460

as the higher levels of soil nitrate are frequently associated with the higher soil-moisture content.

Relationship between Stand Density and Soil-Nutrient Status

Table 3 gives the summarized chemical data for soil-nutrient content at different cacao spacings.

On the whole the nutrient status was higher on the closely spaced plots. Both carbon and nitrogen were high at all spacings, but there is a tendency for their values to be slightly lower on the wider-spaced plots. The soil reaction (pH) dropped slightly but steadily with increasingly wide spacing and exchangeable hydrogen increased correspondingly. Values for base-exchange capacity, and total exchangeable bases were high but tended to be lower on the wider-spaced plots. The C/N ratio increased with wider spacing. Under forest all values were much higher, indicating a certain loss of soil fertility under cacao. The data, however, show that high density of cacao trees did not exhaust soil fertility, but, on the contrary, maintained higher fertility as compared with the lower stand densities.

It is suggested that more leaf litter, more favourable shade conditions, and a more active soil population may account for a marked difference in soil fertility between cacao and forest or between the close and wide cacao spacings.

TABLE 3. *Analysis of Soil Samples from Plots with Different Stand Densities*

Tree spacing ft.	*Depth, in.*	*pH*	*Carbon %*	*Nitrogen %*	*C/N ratio*	*Exchangeable hydrogen (m.e. per 100 gm.)*	*Total exchangeable bases (m.e. per 100 gm.)*	*Base-exchange capacity (m.e. per 100 gm.)*
5×5	0–4	6·45	2·11	0·222	9·6	1·1	6·6	7·7
	4–9	6·30	2·00	0·201	9·9	1·3	5·6	6·9
6×6	0–4	6·40	2·09	0·217	9·6	1·2	5·7	6·9
	4–9	6·30	1·80	0·184	9·8	1·3	3·3	4·6
7½×7½	0–4	6·20	2·06	0·196	10·5	1·6	5·7	7·3
	4–9	6·15	1·74	0·175	9·9	1·3	3·6	4·9
6×7½	0–4	6·25	2·06	0·205	10·0	1·5	5·9	7·4
	4–9	6·15	1·77	0·180	9·8	1·5	3·6	5·1
15×15	0–4	6·00	2·05	0·188	10·9	2·1	4·7	6·8
	4–9	6·10	1·60	0·168	9·5	1·4	3·3	4·7
Forest	0–4	6·40	2·83	0·270	10·5	1·1	10·3	11·4
	4–9	6·35	2·36	0·2238	10·1	1·2	8·5	9·7
	18–24	6·00	1·08	0·140	7·7	2·3	4·3	6·6

Physical data. Quantitative data of physical soil properties are not available, but the following differences were noted. There was little, if any, apparent difference in soil structure between close- and wide-spaced plots. There was, however, a profound difference in structure between cacao and forest soils. Replacement of natural forest by cacao drastically reduces the soil crumb structure and affects physical properties of the shallow-rooting zone, which becomes compact and restricted by the removal of the best-structured and most-aerated part of the profile. This is corroborated by findings, in Trinidad, of Hardy [7], who demonstrated that deterioration of soil fertility under cacao was associated with the reduction of the highly fertile crumb layer. It also appears that the soil fauna is more active under forest; earthworm casts are far more plentiful under forest than under cacao.

Organic litter. The amounts of organic litter under various spacings of cacao were estimated in September 1956 (i.e. before the main leaf-fall) by taking random samples from the 12 × 12-ft. plots. The litter consisted mainly of dry cacao leaves, twigs, and some decomposing organic matter, and, in the widest three spacings, a little green material. The samples also included some earthworm casts, which were difficult to separate. The calculated amounts of litter per acreage are shown in Table 4.

TABLE 4. *Amounts of Organic Litter, and Analysis, on Plots with Different Stand Densities, in lb. per acre*

Tree spacing, ft.	*Fresh weight*	*Air-dry matter*	*Ash incl. soil*	N	P_2O_5	K_2O
5 × 5	26,300	15,520	8,420	158	26	53
6 × 6	18,300	10,800	5,860	110	18	37
6 × 7½	17,400	10,270	5,570	104	17	35
7½ × 7½	17,300	10,210	5,540	104	17	35
10 × 10	14,600	8,610	4,670	88	15	29
12 × 12	14,300	8,437	4,580	86	14	29
15 × 15	8,800	5,190	2,820	53	9	18

Organic litter was most plentiful on the close-spaced plots, even if allowance is made for the soil included in the samples. The amount of leaf litter is directly related to the density of spacing, the correlation coefficient being +0·97, significant at $P = 0{\cdot}01$.

The nitrogen content of the litter is high, averaging 0·6 per cent. N, and it thus adds considerable amounts to the soil. The correlation coefficient between weight of litter and average soil-nitrate content in the 0–4-in. samples is +0·78, significant at $P = 0{\cdot}01$ ($n = 5$).

The amounts of phosphorus and potassium returned to the soil through leaf-fall, even on the closest spacings, are comparatively small but by no means negligible.

It is evident that the higher stand densities of cacao were more suitable for the maintenance of soil fertility, favouring a higher turnover of nutrient elements in the rapid cycle of growth, leaf-fall, leaf-decomposition,

and nutrient reabsorption. Wide spacings reduce litter supply, lower nutrient returns, and do not provide a protective ground mulch cover.

It is of interest to compare the results of Humphries and Rodrigues [8], working in Trinidad, who record 2 tons of fresh cacao leaf-fall per acre in 2½ months during the dry season. They also note that the decomposition of cacao leaves under natural conditions in Trinidad was very rapid and that there was no distinct difference, in the rate of decomposition, between dry and wet seasons.

Light Intensity, Air Temperature, and Relative Humidity

Light intensity was compared on all the spacings under consideration, using apparatus as described by Evans and Murray [9]. A dull rainy day was chosen in order to obtain conditions as uniform as possible. A stationary light meter was checked against the field meter once every 2½ minutes. The field meter was read at 3 points in each sub-plot, i.e. centre east half, dead centre, and centre west half, making no attempt to choose conditions typical of sub-plots as a whole. The results obtained were as follows:

Spacing, ft.	*Percentage light intensity*
15×15	87
7½×7½	64
6×7½	60
6×6	39
5×5	25
Forest	62

The quantitative interpretation of the light effect in terms of cacao performance is not possible because of the number of other interacting factors. Investigation into the effect of light intensity on mature cacao calls for a special experimental design. However, the following observations may be noted.

There is a striking difference in the visual appearance of cacao under different spacings. Cacao trees on plots giving readings of 87 and 60 per cent. light intensity have a bushy and symmetrical habit of growth and are not so high as trees on plots giving lower readings for light intensity, where the trees are of an asymmetrical and elongated type.

Continuous meteorological records showed that differences in depth of shade under close- and wide-spaced cacao were paralleled by differences in air temperature and relative humidity, especially during the dry season. The monthly averages of relative humidity for the plots giving readings of 25 and 87 per cent. light intensity were as follows:

Light intensity	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*
25%	71	62	68	67	78	80	80	72	90	87	84
87%	58	54	58	55	60	75	76	70	77	76	71

Discussion and Conclusions

Considering these results as a whole there can be little doubt that the change from forest to cacao plantation brings about a new equilibrium between a range of interdependent factors such as the relative volume of vegetation, shade conditions, organic litter, soil organic matter, soil nutrients, micro-climatic conditions, at a much lower level than under the forest. For example, the levels of soil organic matter and exchangeable bases have fallen in the course of fourteen years by at least 25 and 50 per cent. respectively.

This, however, does not necessarily mean that it is an unsatisfactory equilibrium for cacao. The level of soil nutrients and especially of soil organic matter is still comparatively high under all five cacao spacings. It compares favourably with the values quoted by Vine [1] for forest soils under rainfall of 70 inches or more. Indeed, in respect of moisture supply, and absence of drought periods—to which cacao is particularly sensitive—conditions under the higher stand densities are slightly more favourable than those found under the secondary forest.

The level of the equilibrium under cacao is determined by the stand density. The evidence provided in this and the previous paper [2] indicates that ease of management, health, and productivity of the crop, as well as the level of soil nutrients, were better at the higher stand densities.

Decline in the level of soil nutrients and soil organic matter with the change from forest to cacao, and also with decreasing stand density of cacao, is considered to be mainly due to a diminished supply of litter and partly to a deterioration of soil biological conditions under cacao. Although no direct quantitative data are available in support of the above statements it is, in the author's opinion, indisputable that both the volume of vegetation and the activity of soil fauna and flora are much lower under cacao than under forest.

Diminution, under cacao, of earthworm activity and of the rate of decomposition of organic litter (mainly leaves), which lead to the characteristic formation of a permanent mulch layer, is one of the notable contrasts between forest and cacao. It is suggested that this difference is due to a reduction in numbers or changes in the nature of soil fauna and flora as a consequence of replacement of a mixed forest vegetation by an exclusively cacao plantation. The levels of soil organic matter, soil nutrients, and shade conditions are only slightly lower under a high stand density of cacao than under the forest. There is no evidence that the level of soil nutrients and the general conditions in cacao plantation deteriorate progressively with time (except for changes of physical soil condition), provided that stand density and a closed canopy are maintained.

In contrast, the equilibrium under a low stand density, with an open canopy, does not appear to be conducive to good growth and satisfactory production. Soil moisture and soil nitrates are particularly affected. These conditions usually lead to less healthy trees, increased infestation by pests, and consequent reduction of litter supply and soil nutrients, tending

ultimately towards complete elimination of cacao and establishment of grass-dominant vegetation. Judging by Nigerian experience, re-establishment of cacao under such conditions is most difficult.

It is generally accepted in Nigeria that good health, growth, and performance of cacao is incompatible with the encroachment of grass/weed ground cover. Visual symptoms suggest that nitrogen deficiency is one of the main factors of cacao deterioration when the canopy is no longer closed and especially when ground is covered by grass-dominant vegetation.

Finally, the results suggest that the factor mainly responsible for the high correlation between stand density and the performance of cacao lies in the higher level of the equilibrium condition which obtains at the higher stand densities.

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REFERENCES

1. H. Vine, *Empire J. Expt. Agric.*, 1953, **21**, 65.
2. J. M. L. Kowal, ibid., 1959, **27**, 27.
3. C. H. Wright, *Ann. Bull. Agric. Dept. Nigeria*, 1929, **8**, 104.
4. W. E. de B. Diamond and K. T. Hartley, ibid., 1930, **9**, 27.
5. —— *Empire J. Expt. Agric.*, 1937, **5**, 264.
6. J. M. L. Kowal, *Some Studies of Soil Fertility in Southern Nigeria*. M.Sc. Thesis, National Library of Wales, 1953.
7. F. Hardy, *Report on Cocoa Research 1945–1951*, I.C.T.A., Trinidad, 1953.
8. E. Humphries and G. Rodrigues, *J. Agric. Sci.*, 1945, **35**, 247.
9. H. Evans and D. B. Murray, *Report on Cocoa Research 1945–51*, I.C.T.A., Trinidad, 1953.

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THE RESPONSES OF *HEVEA BRASILIENSIS* TO FERTILIZERS IN CEYLON

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Summary

The results of experimental work with fertilizers on *Hevea brasiliensis*, carried out since 1940 in Ceylon, have been examined and the responses to fertilizers are presented in terms of girth of the trees prior to tapping. Nitrogen and phosphorus gave generally consistent responses, while there was also some response to potassium (in the presence of phosphorus). The relationship between girth of trees and the yield of latex has also been examined.

MOST of the experimental work with fertilizers on *Hevea brasiliensis* in Ceylon has been carried out since 1951. The correct nutrition of the young trees is of great importance, since the girth of the trees determines when tapping may be commenced and also, within any given clone, the subsequent yield of latex. The direct effects of fertilizers on both girth and yield in an experiment at Dartonfield have been reported by Constable and Hodnett [1]. In most of the work only the effect of fertilizers on the girth of the trees prior to tapping has been studied. This paper summarizes these results and examines the relationship between the girth of the trees and the yield of latex.

Three series of experiments were carried out on commercial estates. The first two series, involving the main plant nutrients—nitrogen, phosphorus, and potassium (N, P, K), each at two levels only, were concerned with determining which nutrients were required by the trees in the areas represented by the various sites selected for the experiments. In the latest series the factors were present each at three levels so that, in addition to the responses at the different sites, some information would be obtained on the forms of the response curves.

The Experiments

The first series (1940–2) consisted of six 2^3 factorial experiments testing all combinations of presence and absence of nitrogen, phosphorus, and potassium. There were four replications at each site. The girth measurements were taken in 1942; the ages and mean girths of the trees at the various sites at this time are given in Table 1. Because of wartime exigencies full details of these experiments are no longer available.

The soils are brown to red gravels and sands overlying biotite gneisses and hypersthene granites (the complex Charnockite series). They are generally deficient in magnesium. Laterite relics are frequent, both as massive boulders and as gravel-size fragments. Many of the slopes are

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steep and the relationship between the soil and the underlying rock is uncertain.

TABLE 1. *2^3 Series of Experiments with Nitrogen, Phosphorus, and Potassium (1940–2). Ages and Mean Girths in 1942*

Estate	*Age of trees (yrs.)*	*Mean girth (in.)*
Clunes . . .	4½	12·64
Mawanella . . .	6	20·72
Pallegodde . . .	4½	13·38
Eladuwa . . .	5½	18·16
Vincit . . .	6	18·64
Yogama . . .	5	11·21

There were seven experiments in the second series (1952–4). The treatments consisted of all combinations of presence and absence of nitrogen and potassium in the presence of phosphorus; untreated plots were also included. A further experiment at Ederapolla compared no fertilizer with phosphorus alone and with nitrogen, phosphorus, and potassium together. Table 2 gives details of the experiments and the sites, the previous manurial histories of which are known to have been very variable. The observations were taken both in 1953 and 1954 except at Hewagam where the experiment was abandoned following severe rat damage in 1953.

Table 3 gives details of the latest series of experiments (1955–7), which consisted of eight standard single-replicate 3^3 trials in pairs on four estates.

The rates of application of the fertilizers in the experiments are shown in Table 4. In the latest series of experiments, the rates of application were increased (doubled) in the second year in view of the rapid growth of the trees accompanied by increased uptake of nutrients [2]. The zero level of phosphorus was not included in this series because it was considered that the absence of phosphorus in the early years would retard growth to an extent which would not be tolerated on commercial estates. In the second and third series a uniform dressing of dolomite was applied to all the experimental sites in order to correct the magnesium deficiency of the soils.

In all the experiments the girth measurements were taken at the standard height of 36 in., using steel measuring tapes. Yields of latex were not recorded for these experiments.

Results

The mean girth responses to nitrogen, phosphorus, and potassium are shown in Table 5, together with the interactions.

In the first series the main response was to phosphorus, which appears to be fairly consistent. There also appears to be a general, although smaller, response to nitrogen. The effect of potassium seems to be very erratic, as reflected in the larger standard error, the average response being small and negative. It is likely that these responses to potassium

TABLE 2. *Series of Experiments on Commercial Estates (1952–4)*

Site	*Soil type*	*Planting material*	*Layout**	*Spacing of trees*	*Plot size*		*Age of trees in 1953 (years)*	*Mean girths (in.)*		*Remarks*
					Rows	*Trees*		*1953*	*1954*	
Lochnagar	Limestone	Kepitigalla Polyclone seed	5×5 L. Sq.	6′×5o′	2	14	3	3·42	4·50	
Kepitigalla	Clay	Kepitigalla Polyclone seed	5×5 L. Sq.	12′×20′	5	5	3	4·00	7·23	
Ederapolla	Kelani Valley Gravelly/quartzitic	PB 86 illegitimate seedlings	(Contour rows)		1	50	3	5·90	6·22	Top-budded with LCB 870 and removal of original crown in 1953.
Degalessa	Kelani Valley Gravelly/quartzitic	PB 86 buddings	6 R.B.	30′×8′	3	17	3	4·94	7·14	
Hewagam	Kelani Ganga flood plain	WG 6278 buddings	5 R.B.	10′×30′	2	10	3	6·46	..	Experiment abandoned in 1954, following rat damage.
Epping Forest	Kalu Ganga flood plain—Lateritic	PB 86 buddings	5×5 L. Sq.	10′×20′	5	5	3	5·67	8·64	
Ambatenne	Kalutara district Gravelly/concretionary	Kepitigalla Polyclone seed	5 R.B.	12′×20′	3	15	6	11·97	16·16	At least two full years' manuring prior to treatments.
Mirishena	Kalu Ganga flood area—Sandy	G.L. 1 buddings	4 R.B.	15′×18′	3	50	4	4·42	6·97	One year's full manuring prior to treatments.

* L. Sq. = Latin square; R.B. = randomized blocks.

TABLE 3. *3^3 Series of Experiments with Nitrogen, Phosphorus, and Potassium (1955–7)*

Estate	*Land and soil type*	*Planting material*	*Spacing of trees*	*Plot size*		*Exp.*	*Age of trees in 1956 (years)*	*Mean girths (in.)*	
				Rows	*Trees*			*1955*	*1956*
Nakiadeniya	Steep land.	PB 86	12′×18′	1	10	1	3	5·98	9·19
						2	3	5·30	8·57
Padukka	Rolling land. Brown sand on laterite.	PB 86	12′×18′	1	10	1	3	6·11	9·53
							3	5·25	8·41
Palmgarden	Rolling land. Quartzite sands with biotite from massive intrusions.	PB 86	13′×14′	1	10	2	3	5·10	7·41
						2	4	8·56	11·19
Mahawale	Very steep land. Sand and gravel on quartz and granite.	PB 86	14′×14′	1	10	1	3	6·46	9·52
			11′×20′			2	4	3·62	5·68

TABLE 4. *Rates of Application of Fertilizers in the Experiments (oz. per tree)*

Fertilizer	*Series*		
	1940–2	*1952–4*	*1955–7*
	1	*2*	*3*
Ammonium sulphate (20% N) . . .	0, 27	0, 20	0, 4, 8
Saphos phosphate (30% P_2O_5) (Egyptian Rock Phosphate)	0, 19	0, 16	2, 4, 8
Muriate of potash (50% K_2O) . . .	0, 11	0, 8	0, 2, 4

1. Total application.
2. Applied in four *pro rata* doses each year.
3. Rates in 1955; these rates were doubled in 1956.

are related to the widespread deficiency in magnesium which has become increasingly apparent within recent years. The two-factor interactions do not appear to be appreciable, but there was a consistently large three-factor interaction. Table 6 shows that responses to nitrogen were generally reduced by the presence of phosphorus when potassium was absent, whereas when it was present they were increased. Alternatively, the situation may be viewed as a reduction in the response to nitrogen by potassium when phosphorus was absent but an increase in the response to nitrogen due to potassium when phosphorus was present, i.e. the nitrogen–potassium interaction was negative in the absence of phosphorus but positive in its presence. The latter received some support from the second series, especially in 1954.

Following the results of this series of experiments, the use of phosphorus became general on estates, ½–1 lb. Saphos phosphate being placed in the hole at planting. This application should supply the needs of the trees for 1 to 2 years.

In the second series of experiments there were responses to phosphorus alone and also to nitrogen and potassium (in the presence of

TABLE 5. *Effects of Nitrogen, Phosphorus, and Potassium on Girth of Trees (inches)*

1st Series	*Main effects*			*Interactions*			
	N	P	K	NK	NP	PK	NPK
Clunes	−0·18	+0·22	−0·52	−0·02	−0·28	−0·42	+0·28
Mawanella	+0·65	+0·20	+0·30	−0·30	−0·30	−0·15	+0·55
Pallegodde	+0·48	+0·78	−1·02	+0·08	+0·18	+0·08	+0·28
Eladuwa	+0·42	+1·08	−0·22	+0·68	−0·12	−0·08	+0·52
Vincit	+0·70	+1·10	+0·55	+0·10	+0·15	0·00	+0·25
Yogama	−0·15	+0·40	+0·15	+0·35	0·00	−0·20	+0·10
Mean	+0·32	+0·63	−0·13	+0·15	−0·06	−0·13	+0·33
S.E.	±0·158	±0·167	±0·237	±0·136	±0·084	±0·072	±0·071

	N[a]		P[b]		K[a]		NK[a]	
2nd Series	*1953*	*1954*	*1953*	*1954*	*1953*	*1954*	*1953*	*1954*
Lochnagar	+0·05	+0·08	+0·07	+0·27	−0·02	−0·04	−0·06	−0·12
Kepitigalla	+0·39	+1·00	+0·07	−0·04	+0·03	+0·18	+0·08	+0·14
Ederapolla	..	..	+0·27	+0·05	..	..	..	..
Degalessa	+0·68	+1·74	+0·02	+0·71	+0·12	+0·49	+0·12	+0·47
Hewagam	+0·40	..	+0·05	..	−0·09	..	−0·32	..
Epping Forest	+0·11	+0·17	−0·04	+0·53	+1·05	+1·84	−0·08	−0·08
Ambatenne	+0·77	+1·04	+1·18	+1·77	+0·05	−0·17	+0·31	+0·40
Mirishena	+0·30	+0·42	+0·48	+1·20	+0·13	+0·28	+0·15	+0·04
Mean	+0·39	+0·74	+0·26	+0·64	+0·18	+0·43	+0·03	+0·14
S.E.	±0·101	±0·260	±0·144	±0·247	±0·148	±0·298	±0·077	±0·100

	N'[a]		P'		K'[a]		N'K'[a]	
3rd Series	*1956*	*1957*	*1956*	*1957*	*1956*	*1957*	*1956*	*1957*
Nakiadeniya	+1·14	+1·30	−0·01	+0·06	+1·54	+1·99	+1·13	+1·30
	+0·98	+1·51	+0·62	+0·91	−0·16	−0·23	−0·30	−0·53
Padukka	+0·37	+0·48	+0·71	+0·68	+0·56	+0·61	−0·12	−0·07
	+1·01	+1·14	−0·30	−0·38	+0·16	+0·39	−0·35	−0·48
Palmgarden	+1·01	+1·52	−0·21	−0·12	+0·09	+0·12	+0·05	−0·18
	+0·69	+0·86	−0·02	−0·03	+0·01	−0·09	+0·35	+0·65
Mahawale	+0·39	+0·11	+0·16	+0·38	+0·02	+0·21	−0·33	−0·40
	+0·68	+0·27	+0·26	−0·09	+0·24	+0·03	+0·13	+0·10
Mean	+0·78	+0·90	+0·15	+0·18	+0·31	+0·38	+0·07	+0·05
S.E.	±0·105	±0·197	±0·129	±0·156	±0·191	±0·248	±0·175	±0·224

[a] In presence of phosphorus. [b] Response to phosphorus alone.
' Linear component.

phosphorus). There was considerable variation from site to site, which was more marked in 1954. In most cases where responses were observed, they were larger in 1954 than in 1953, indicating a change in response with age and development. Part of the variability in response from site to site within years may thus be ascribed to different ages of the trees; the experiment at Ambatenne, for example, was on much larger and older trees. The nitrogen–potassium interaction (in the presence of phosphorus) was small on the average, but tended to be positive, as observed in the first series.

TABLE 6. *Effect of Nitrogen on Girth of Trees in the Presence and Absence of all Combinations of Phosphorus and Potassium: 2^3 Series (1940–2)*

Girth responses to Nitrogen (in.)

	Without potassium			*With potassium*			
	Phosphorus		*Diff.* (0)	*Phosphorus*		*Diff.* (1)	*Diff.* (1)–(0)
Estate	p_0	p_1	(p_1–p_0)	p_0	p_1	(p_1–p_0)	NPK × 4
Clunes .	+0·4	−0·7	−1·1	−0·2	−0·2	+0·0	+1·1
Mawanella .	+1·8	+0·1	−1·7	+0·1	+0·6	+0·5	+2·2
Pallegodde .	+0·5	+0·3	−0·2	+0·1	+1·0	+0·9	+1·1
Eladuwa .	+0·4	−0·9	−1·3	+0·7	+1·5	+0·8	+2·1
Vincit .	+0·7	+0·5	−0·2	+0·4	+1·2	+0·8	+1·0
Yogama .	−0·4	−0·6	−0·2	+0·1	+0·3	+0·2	+0·4
Mean . .	+0·57	−0·22	−0·79	+0·20	+0·73	+0·53	+1·32

A general response to nitrogen was observed in the third series of experiments. This response appears to be consistent from site to site in both years. In the second year (1957) the responses were increased except at Mahawale where the trees had become affected by white root-rot disease (*Fomes lignosus*). If the latter results are omitted, the average increase in response was 0·27±0·080 in. This effect is similar to that observed in the second series, although in this series it will be due in part to the increased rates of application of nitrogen in the second year. The mean girths at the three levels of nitrogen (Table 7) show the form of the average response curve.

At most of the sites the phosphorus requirements appear to have been supplied by the lowest level applied (p_1). (The girths in the absence of phosphorus would certainly have been of interest.) In these circumstances the average response curve (Table 7) over the range of dressings used is not well determined. The second experiment at Nakiadeniya and the first at Padukka, however, did show responses to the additional dressings. The responses were very similar in both years.

There was generally some response to potassium in both years. The first experiment at Nakiadeniya was outstanding for the large response observed, especially to the second increment (k_2–k_1). If this experiment is included, the average response curve (Table 7) is linear in 1957. There

TABLE 7. *Mean Girths at the Different Levels of Nitrogen, Phosphorus, and Potassium (in.): 3^3 Series (1955–7)*

	Nitrogen			*Phosphorus*			*Potassium*[a]		
	n_0	n_1	n_2	p_1	p_2	p_4	k_0	k_1	k_2
1956 .	8·21	8·88	8·99	8·67	8·57	8·82	8·53	8·65	8·67
1957 .	11·61	12·25	12·51	12·08	12·03	12·26	12·03	12·15	12·18

[a] Excluding first experiment at Nakiadeniya.

was no evidence that the responses at the remaining sites were inconsistent with a single overall value. These results are generally similar to those observed in the second series, where a basal application of dolomite

was also applied, and they appear to be generally more stable than the effects of potassium observed in the first series, where no treatment for possible magnesium deficiencies was given.

The interactions between nitrogen and potassium, which were observed in the presence of phosphorus, were very variable in this series and somewhat obscure.

Relationship between Girth of Trees and Yield of Latex

It is generally recognized that there is a marked relationship between girth and yield. Data from an experiment on density of planting in Malaya [3] gave the high values of the correlation coefficient r shown in Table 8.

TABLE 8. *Correlations between Girth and Yield (Data of Mann* [3])

Girth in .	1937	'38	'39	'40	'36	'36	'36	'36	'35
Yield in .	1937	'38	'39	'40	'37	'38	'39	'40	'37
r . .	0·91	0·97	0·99	0·99	0·92	0·92	0·91	0·86	0·93
S.E. (4 d.f.) .	±0·21	±0·12	±0·04	±0·08	±0·19	±0·20	±0·21	±0·25	±0·18

Tapping commenced in 1937.

When fertilizers are used, they may influence directly the flow of latex or they may act indirectly by increasing the girth of the trees, or probably in both ways. In a fertilizer experiment at Dartonfield, Ceylon, measurements of girth and yield were taken [1]. Analysis of covariance of the *total* yield (1944–7) on the girth in 1944, immediately prior to tapping, shows that there is a significant regression ($b = 157 \pm 32{\cdot}1$ lb. per acre per in. of girth) and that the fertilizer effect on the yield of latex is accounted for by the effect on the girth of the trees, there being no evidence for fertilizer effect after adjustment of the yields for girth. However, as might be expected, the regression of the total yields for the next three-year period (1948–50) on the girths in 1944 was not significant ($b = 67{\cdot}8 \pm 41{\cdot}2$ lb. per acre per inch of girth) and there was also a significant treatment effect after adjustment; but the association is much closer if the girths in later years are used. Girth is thus a good indicator of future yield, at least for a few years.

This relationship between girth and subsequent yield is of considerable value in the planning of experimentation with fertilizers, since it means that considerable progress towards the formulation of a fertilizer policy for rubber can be made by experimenting on young trees prior to tapping. In turn, this simplifies the field work, since fortnightly yield recording under skilled supervision, and the associated loss of rubber, are eliminated, so making it possible to carry out more experiments and to site them on commercial estates.

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REFERENCES

1. D. H. Constable and G. E. Hodnett, *Empire J. Expt. Agric.*, 1953, **21**, 131.
2. —— *Girth and growth measurements as an aid to manurial diagnosis in tropical horticulture.* Report of 14th Internat. Hort. Congr., Netherlands, 1955, p. 1346.
3. C. E. T. Mann, *Rubb. Res. Inst. Malaya, Ann. Rept.*, 1940, p. 47.

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SIMPLIFIED RATIONS FOR POULTRY AT PASTURE

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Summary

This paper covers a series of four experiments between 1948 and 1953, investigating the contribution of proteins, minerals, and vitamins provided by pasture, for growing and laying poultry.

Experiment 1 was concerned with the performance of laying hens fed either mash and grain or grain alone while kept in fold units either on wood floors or on pasture. When fed grain alone, 10-month-old pullets laid fewer and smaller eggs and lost body weight compared with similar pullets fed a mash and grain ration, whether pasture was available or not. Egg production, egg size, and body weight quickly recovered when a mash and grain ration was fed. A limited recovery was produced by the addition of 0·3 per cent. mineral mixture to the grain ration when birds had access to grazing in the post-experimental period.

In Experiment 2 the value of a fishmeal supplement to a cereal and mineral diet for laying birds on pasture was studied. During the first laying year birds fed cereals and minerals produced significantly fewer eggs than birds on a diet of cereals, minerals, and 10 per cent. fishmeal.

Comparison of a normal mash and grain diet with one composed mainly of wheat and minerals, for growing and laying pullets on pasture, was made in Experiment 3. Body weights at point-of-lay were not significantly different, but birds fed the former ration came into lay 2 weeks earlier and laid more eggs during the first laying year.

In Experiment 4 a study was made of the performance of laying hens when cod-liver oil was omitted from their ration during the summer. This resulted in birds on wood floors producing fewer eggs during their first and second laying years, than birds folded on pasture. Birds grazing mature herbage on an area cut for silage laid fewer eggs than birds grazing short herbage produced either by sheep grazing or by gang-mowing.

From the results of the four experiments it is concluded that a diet of wheat and minerals is adequate for the growth of pullets even when grazing is restricted to that within fold units, but that a protein supplement is necessary for high egg yields. During the summer months laying hens can also obtain appreciable quantities of carotene from young herbage.

EGG-PRODUCTION costs could be lowered if cheap simple rations proved to be adequate for poultry grazing on young pasture. Poultry cannot digest large amounts of herbage because of its high fibre content, and thus only a small part of their total energy requirements can be supplied by herbage. Cereal grains are their chief source of energy and to produce a balanced diet these must be supplemented with expensive foods rich in proteins, minerals, and vitamins. The contribution, by pasture, of proteins, minerals, and vitamins was the subject of these investigations; the botanical data will be presented separately.

Birds on pasture were fed on cereals alone in the first experiment and on cereals plus a mineral supplement in Experiments 2 and 3, whilst in the fourth experiment their ration was deficient in vitamins A and D. Limestone, flint grit, and water were freely available in all experiments.

In all the experiments the birds were weighed individually, usually at

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monthly intervals. They were kept in fold units and the number and weight of eggs produced per fold were recorded daily. A sample of each batch of mash and grain was chemically analysed.

Experiment 1

In this experiment the performance of laying hens was measured when fed either mash and grain or grain alone while kept either on wood floors or on pasture. From the commencement of laying in November 1948, fifty-six 10-month-old Rhode Island Red × Light Sussex laying pullets, in folds on grass, were fed 84 gm. of a proprietary mash plus 70 gm. of mixed grain (half maize and half wheat) daily per bird. On 16 March 1949 these pullets were allocated to the four treatments, with seven birds per fold and two folds per treatment. The folds on grass were moved daily across a rough-stalked meadow grass—white clover sward.

The composition and chemical analyses of the mash and the grain mixture fed during the experiment are given in Table 1. The daily

TABLE 1. *Composition and Chemical Analyses of Mash and Grain Feeds in Experiments 1 and 2, per cent. air-dried*

	Experiment 1		*Experiment 2*		
Constituents	*Layers' Mash*	*Grain mixture*	*Cereals plus minerals*	*Cereals plus minerals plus fishmeal*	*Grain mixture*
Oats	..	..	..	..	50
Wheat	..	50	..	..	50
Kibbled yellow maize	..	50	..	..	..
Maizemeal	10	..	..	..	..
Bran	30	..	21·4	19·3	..
Middlings	29·8	..	42·8	38·6	..
Barley meal	10	..	21·4	19·3	..
Sussex ground oats	10	..	10·7	9·7	..
Whale meat meal	10	..	..	..	..
Fishmeal	..	..	..	9·7	..
Mineral mixture	..	..	3·7	3·4	..
Salt	0·2	..	..	..	..
Proximate analysis					
Moisture	5·2	6·5	12·2	11·4	12·8
Crude protein	18·9	11·3	12·6	16·9	11·2
Ether extract	1·6	1·6	3·5	3·5	..
Crude fibre	11·8	1·5	9·4	8·3	5·1
Total ash	6·9	1·4	7·5	8·4	..
Silica-free ash	6·5	1·3	7·0	8·0	..
Ca	0·6	0·1	1·1	1·6	..
P	1·2	0·3	0·9	1·1	..
Cl (as NaCl)	0·6	0·1	0·8	0·9	..

rations per bird were: (1) 84 gm. of mash and 70 gm. of grain mixture, or (2) 56 gm. (increased after 4 weeks to 70 gm.) of coarsely ground grain and 84 gm. (reduced after 4 weeks to 42 gm.) of a whole-grain mixture.

The experimental period terminated on 4 May 1949, when all folds

were put on grass and moved daily over the sward, and all the birds received the same daily ration of 84 gm. of a proprietary mash plus 70 gm. of mixed grain (half oats and half wheat) per bird.

Results. Fig. 1 shows the changes in the level of egg production and Table 2 the number and average weight of eggs laid per bird during

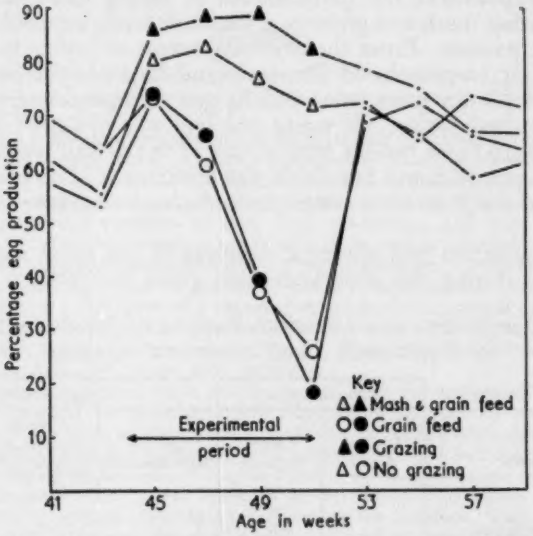

FIG. 1. Percentage egg production before, during, and after Experiment 1.

each period. Many of the birds fed grain alone had stopped laying by the end of the seventh week whether they had access to grazing or not, whereas all the hens fed on mash and grain continued to lay at a high level throughout the experimental period.

During the experimental period, the average weight of the eggs laid by the birds on the grain ration decreased, while those laid by the birds on the mash and grain ration increased in weight. All the birds with access to grazing laid eggs with dark-orange yolks, while those on wood floors laid eggs with pale-yellow yolks.

Fig. 2 shows that the body weight of the hens fed grain alone decreased rapidly, but when they were returned to a mash and grain ration mean egg weight and body weight increased to equal that of the control birds.

There were no deaths during the experiment. After 4 weeks of eating grain alone the birds on wood floors began feather-pecking, but the birds with access to grass did not. The pasture was scratched and grazed much more vigorously by the birds fed only grain.

The most serious deficiency in the grain ration was thought to be the low level of common salt and phosphorus content. Therefore, during the post-experimental period seven of the birds which had been fed only grain and kept on grass were folded on grass and fed, per bird,

TABLE 2. *Number and Mean Weight (gm.) of Eggs Laid per Bird per Period in Experiment 1.*

Period	*Dates*	*No. of weeks*	*Number, and mean weight* (**heavy type**)			
Pre-experimental (all fed mash plus grain on grass)	18.2.49 to 16.3.49	4	16·5 **62**	18·6 **62**	15·4 **62**	18·6 **62**
			Mash plus grain		*Grain only*	
			On wood	*On grass*	*On wood*	*On grass*
Experimental	17.3.49 to 4.5.49	7	38·4 **63**	42·4 **66**	25·6 **61**	26·6 **60**
Post-experimental (all fed mash plus grain on grass)	5.5.49 to 6.7.49	9	44·7 **65**	46·1 **67**	39·3 **67**	37·1 **68**

a daily ration of 70 gm. of ground grain mixture, supplemented with 0·5 per cent. of a mineral mixture (4 parts steamed bone flour plus 1 part common salt), together with 42 gm. of the whole-grain mixture (half maize and half wheat). These seven birds reached an egg-production rate of 45 per cent., whereas their seven companions in the other fold, which had been similarly fed during the experimental period, but which were changed to the mash and grain ration, reached a level of 65 per cent. While the birds receiving the mash and grain ration soon produced eggs weighing from 58 to 67 gm., the birds on the grain and mineral treatment continued to lay eggs weighing from 56 to 60 gm.; these birds only maintained their body weight, whilst the former made good weight gains.

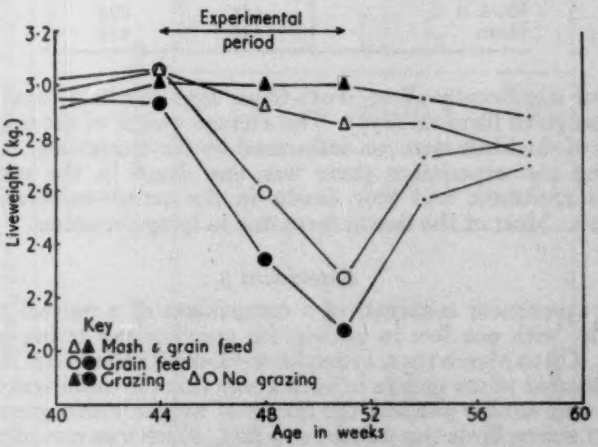

FIG. 2. Liveweight changes before, during, and after Experiment 1.

It was concluded that the addition of 0·3 per cent. of this mineral mixture (based on total eaten) to a cereal diet was insufficient to support a high level of egg production, and that in future experiments more minerals should be added.

Experiment 2

This experiment tested the value of a fishmeal supplement to a cereal and mineral diet for laying birds on pasture. On 4 April 1950 fifty-two 24-week-old Brown Leghorn × Light Sussex point-of-lay pullets were allocated at random to four folds, each containing thirteen birds. All the birds were fed a normal mash and grain diet until 3 May 1950, when the birds in two folds were fed ground cereals plus minerals and those in the other two the same ration plus fishmeal. Each bird was given a daily ration of 70 gm. of the mash for 16 weeks, then 77 gm. until the end of the experiment, which lasted 80 weeks. The daily ration of the grain mixture was 56 gm. for all the birds. The composition and chemical analyses of the feeds have been given in Table 1 (p. 159). Throughout the experiment all the birds were folded over short pasture.

Results. The birds came into full lay immediately the experimental treatments started, and during the first laying year those fed cereals and minerals laid 154 eggs per bird compared with 182 for those fed fishmeal in addition. During the final 6 months the latter sustained egg production better. In 80 weeks (Table 3) the birds fed cereals plus minerals

TABLE 3. *Number of Eggs Laid per Bird during Experiment 2*

	Cereals plus minerals	*Cereals and minerals plus fishmeal*
Block A . . .	243	280
Block B . . .	235	275
Mean . . .	239	277

produced significantly ($P < 0.05$) fewer eggs per bird (239) than the birds also given fishmeal (277). The average weight of the eggs and the weights of the birds were not influenced by the treatments.

During the experiment there was one death in the cereals-and-minerals treatment and four deaths in the cereals-minerals-fishmeal treatment. Most of the deaths were due to lymphomatosis.

Experiment 3

This experiment consisted of a comparison of a normal mash and grain diet with one low in protein for growing and laying pullets on pasture. On 20 March 1952, 110 eight-week-old Rhode Island Red pullets were allocated to ten groups in such a way that the mean weights of the groups were similar and also the ranges of weight within groups. Each group of eleven birds was housed in a fold, which was moved daily over short herbage. Five folds were allocated at random to each of two

TABLE 4. *Composition and Chemical Analyses of Mash and Grain Feeds in Experiments 3 and 4, per cent. air-dried*

Constituents	*Experiment 3*						*Experiment 4*			
							Mash		*Grain*	
	Growing pullets			*Laying hens*			*from 6.10.49 to 19.7.50*	*from 20.7.50 to 10.10.50*	*from 6.10.49 to 1.1.50*	*from 2.1.50 to 10.10.51*
Wheat	..	..	100	..	..	100	..	..	50	67
Oats	..	..	..	..	..	..	..	..	50	..
Maize	..	..	..	..	..	..	..	..	..	33
Proprietary mash	100	95	..	100	95	..	90	80	..	..
Bran	..	..	..	..	..	..	10	20	..	..
Mineral mixture	..	5	..	..	5	..	..	..	..	..
Proximate analysis										
Moisture	10·8	10·5	11·7	11·5	11·4	12·6	10·6	11·9	10·4	12·9
Crude protein	16·2	15·9	11·5	16·8	16·1	10·8	16·0	16·0	12·1	10·5
Ether extract	4·3	3·5	..	3·9	3·5	..	4·0	3·3	4·1	2·5
Crude fibre	5·9	6·0	2·1	6·3	6·0	2·1	7·0	7·5	6·7	2·5
Total ash	4·7	8·8	..	5·5	7·9	..	5·9	5·8	2·6	1·7
Silica-free ash	4·3	8·3	..	4·9	7·3	..	5·4	5·4	1·9	1·6
Ca	0·7	2·1	..	0·8	1·6	..	1·0	0·9	0·1	0·1
P	0·6	0·7	..	0·7	0·8	..	0·7	0·7	0·4	0·4
Cl (as NaCl)	0·2	1·0	..	0·4	0·8	..	0·3	0·4	0·1	0·1

treatments: (1) a normal diet of wheat plus mash; and (2) a diet of wheat plus a little mash with minerals.

Table 4 gives the chemical composition of the mashes and wheat used during the growing and laying periods. From the start each bird on the

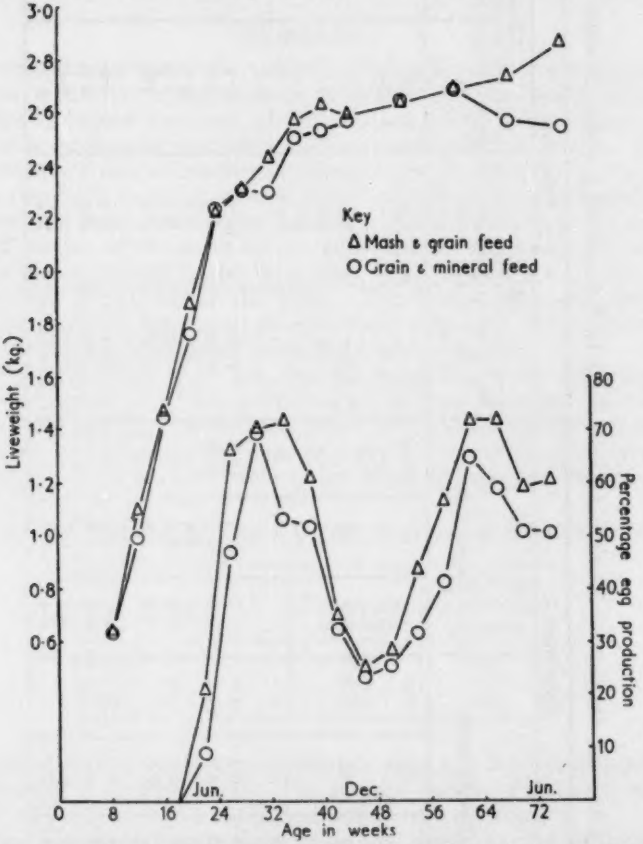

FIG. 3. Liveweight changes and percentage egg production during Experiment 3.

normal diet received 42 gm. of a proprietary growers' mash plus 28 gm. of wheat per day. The quantities were gradually increased over 14 weeks to 84 and 56 gm. respectively. The growers' mash was replaced by an equal ration of a proprietary layers' mash two weeks later (10 July 1952), this level of feeding being continued for the rest of the experiment. For birds on Treatment 2, the daily ration of proprietary mash with 5 per cent. of a mineral supplement was kept constant at 14 gm. per bird throughout the experiment; in addition each bird had initially 56 gm. of wheat daily, gradually increased up to 126 gm. on 24 June 1952 and continued at this level until the end of the experiment on 9 July 1953.

Results. Fig. 3 shows that there was very little difference in the growth of the birds on the two treatments; and at the end of the growing period on 10 July 1952 there was no significant difference (Table 5) between the live-weight gains of birds reared on the control diet (1) and those fed mainly on cereals (2). Under Treatment 1, 6·5 kg. of mash

TABLE 5. *Mean Live-weight Gain and Egg Production during Experiment 3*

	Normal diet	*Mainly wheat diet*	*S.E.*
Live-weight at 8 weeks of age, gm. . . .	636	635	..
Live-weight gain from 8 to 24 weeks of age, gm.	1,587	1,600	±23·6
Live-weight gain from 8 to 76 weeks of age, gm.	2,228	1,913	±43·0
Number of eggs per bird up to 76 weeks of age .	201	168	±6·1

plus 4·3 kg. of wheat were used to rear a bird from 8 to 24 weeks of age, while under Treatment 2 the corresponding figures were 1·6 kg. of fortified mash and 9·1 kg. of wheat. Birds on the control diet had put on significantly ($P < 0.01$) more weight by the end of the experiment than those fed mainly on wheat.

The birds under Treatment 1 came into lay approximately 2 weeks before the birds on Treatment 2, and, in addition, the egg production of the former was consistently better throughout the first laying year (Fig. 3). Feather-pecking occurred for a period in one replicate of Treatment 2 and, although no deaths occurred, egg production was depressed. During the first laying year the average of 201 eggs laid by a bird on the normal diet was significantly ($P < 0.05$) more than the average of 168 eggs for a bird on the simplified diet (Table 5).

From 8 to 24 weeks of age only one bird died, but during the first laying year mortality was 26 per cent. with the normal diet and 16 per cent. with Treatment 2; the causes of deaths were, however, apparently unrelated to the treatments.

Experiments 2 and 3 showed that grazing hens would lay satisfactorily when fed on rations composed mainly of cereals plus minerals, but that supplementing these rations with protein concentrates improved egg production.

Experiment 4

This experiment was a study of the performance of laying hens when cod-liver oil was omitted from their ration during the summer. On 4 August 1949, 210 fourteen-week-old Brown Leghorn × Light Sussex pullets were allocated at random to fourteen folds (15 birds per fold). On 6 October 1949 two folds were placed on wood floors and the remainder were folded across swards where the surplus herbage was controlled: in one block by frequent gang-mowing; in one by sheep-grazing; and in one by cutting for silage. There were four folds on each of these managements during 1950 and 1951; the experiment finished on 10 October 1951.

All birds were fed on the same ration. The composition and chemical analyses of the mashes and grain mixtures have been given in Table 4 (p. 163). In an attempt to prevent feather-pecking 10 per cent. of bran was added to the mash from the start and 63 gm. of the mixture per bird was fed daily. After 41 weeks, from 20 July 1950 until the end of the experiment, the bran was increased to 20 per cent. and 70 gm. of the mash was fed per bird daily. The proprietary mash contained cod-liver oil during the winter period only (6 October 1949 to 2 January 1950; and 20 September 1950 to 11 April 1951). At first, 70 gm. of a mixture of oats and wheat was fed also to each bird daily, but after 2 January 1950 a mixture of maize and wheat was fed at the daily rate of 56 gm. per bird.

Ten herbage samples, each from 12·6 sq. in., were cut fortnightly during 1950 and monthly during 1951, at soil level in front of each fold. After bulking, sub-samples were taken for botanical analysis and dry-matter and crude-protein determinations.

Results. The birds on wood floors produced the fewest eggs. Table 6

TABLE 6. *Number of Eggs Produced per Bird* in Experiment 4*

Number of eggs per bird during periods when	*Folds on wood floors*	*Folds on pasture; surplus herbage controlled by*		
		gang-mowing	*sheep-grazing*	*silage-cutting*
C.L.O. added to ration . . . (6.10.49 to 2.1.50 and 20.9.50 to 11.4.51 = 311 days)	93	102	100	96
S.E. of mean, ± . . .	7·4	5·2	5·2	5·2
C.L.O. omitted from ration . . (3.1.50 to 19.9.50 and 12.4.51 to 10.10.51 = 425 days)	160	258	253	222
S.E. of mean, ± . . .	11·5	8·1	8·1	8·1

* Sum of $\frac{\text{total number of eggs per fold during each week}}{\text{number of birds surviving at end of week}}$.

and Fig. 4 show that their production fell below that of the grazing birds principally during the periods when cod-liver oil was omitted from the ration ($P < 0{\cdot}001$). All the birds were exposed to the same amount of sunlight and so had the same opportunity to form vitamin D. The amount of carotene supplied by the yellow maize was evidently insufficient to support maximum egg production; the grazing birds supplemented their diet by eating carotene-rich herbage. The eggs of the birds without access to pasture had pale-yellow yolks while those of grazing birds had dark-orange yolks.

The birds grazing the areas cut for silage produced fewer eggs ($P < 0{\cdot}05$) than did those on the sheep-grazed or gang-mown areas; this was attributed to feather-pecking and the maturity of the herbage. The birds on the sheep-grazed areas produced as many eggs as those on the gang-mown areas; for the sake of brevity, the results of the former have been omitted from Fig. 4.

The body weights of the birds on wood floors fell below those of the

birds at grazing, when cod-liver oil was excluded from the ration. When it was included the birds on wood floors made up this deficiency in weight. Birds grazing the areas cut for silage lost weight more rapidly than those grazing the short young herbage on the gang-mown or sheep-grazed areas.

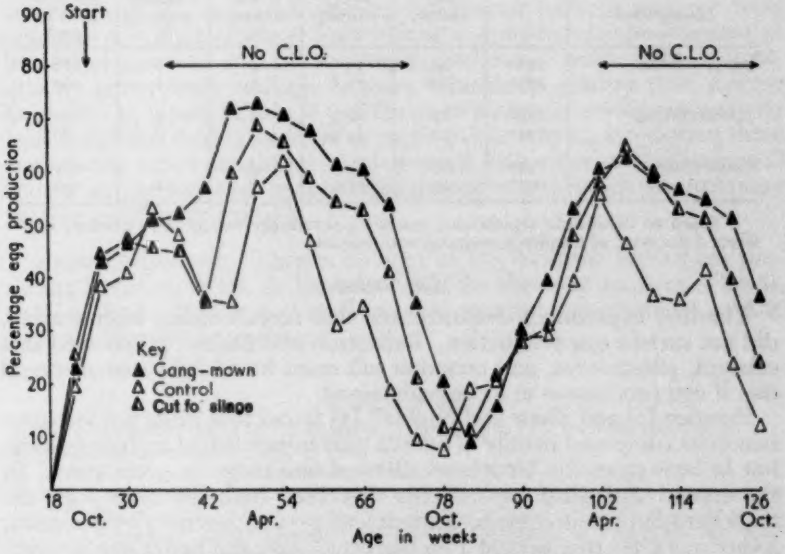

FIG. 4. Percentage egg production during Experiment 4.

The mortality rate was 10 per cent. for birds on wood floors and 9, 11, and 14 per cent. for birds grazing the gang-mown, sheep-grazed, and silage-cut areas respectively. Lymphomatosis, egg peritonitis, and crop-binding (with straw litter in the case of the birds on wood floors) were the main causes of death, and were equally distributed among the treatments.

The mean amount and the average composition of the herbage[1] on offer during the growing seasons is summarized in Table 7. The herbage with the highest crude protein was produced on the gang-mown area. There was more dry matter, with a lower crude-protein content, on offer on the swards cut for silage than on swards under the other two pasture managements. It was not possible to measure the amount of herbage remaining after one day of poultry-grazing because the herbage was contaminated with soil and dung and the roots had been scratched out of the ground.

[1] Since poultry graze more closely than other stock, a new herbage sampling method was devised to cut all the herbage down to soil level: hence the herbage samples contained all the old stems and leaves found in the bottom of a sward. Consequently all the crude-protein contents were lower and the dry-matter yields higher than those obtained by the common herbage sampling methods, by which only the top portion of the swards is cut.

TABLE 7. *Amount and Composition of Herbage on Offer to Birds Folded on Grass in Experiment 4*

Management of sward	*Year*	*Description of green herbage*				*Dry matter on offer per bird per day (gm.)*
		Dry matter, %	*Crude protein in dry matter, %*	*White* clover, %*	*Unsown* grasses, %*	
Gang-mowing	1950	29	13·8	4	6	108
	1951	29	13·1	5	18	100
Sheep-grazing	1950	29	12·3	2	3	110
	1951	30	11·9	1	7	87
Silage-cutting	1950	27	11·5	3	4	177
	1951	29	11·0	8	14	138

* Based on dry-weight separations; remaining percentage mainly sown grasses; only about 1 per cent. of unsown non-gramineous species.

Discussion

The first experiment demonstrated that cereals alone, with grazing, did not sustain egg production. Robertson and Baskett [1] showed that calcium, phosphorus, and common salt must be added to an all-cereal diet if egg production is to be maintained.

Prentice [2] and Shaw and Nightall [3] found that birds fed low-protein diets composed mainly of cereals plus minerals had high egg yields, but in both cases the birds were allowed free range in grass runs. In the second and third experiments described here the diets with the higher crude-protein content (Experiment 2—16·4 against 13·7 per cent.; Experiment 3—16·4 against 13·0 per cent.) gave the better egg production. Carpenter, Duckworth, and Ellinger [4] have suggested that 14 per cent. is the minimum crude-protein level needed to sustain normal egg production. It is suggested that the birds on the lower protein diets could not obtain the extra protein they required from the herbage, as they appear to have done in the experiments of Prentice [2], and Shaw and Nightall [3], because their grazing was severely limited to the small area within a fold, which quickly became fouled. Probably birds confined in folds were forced to eat herbage of relatively low-protein content (e.g. 15 per cent.), whereas those on free range could select that of much higher protein content (e.g. 25 per cent.). Assuming a daily herbage dry-matter intake of 20 gm. per bird [5] the difference in herbage-protein intake between folded and ranged birds could make a difference of 7 per cent. in their total protein intake. A further reason for the difference between the results presented here and those of other workers may be the wide variation in crude-protein content between different batches of cereals.

Growing pullets have a lower protein requirement than laying hens, and for that reason the high- and low-protein diets of Experiment 3 produced similar growth from 8 weeks up to point-of-lay [6]. It is during the growing period that the greatest saving of protein concentrates can be achieved. If hatched in February and March, the birds' growth

coincides with the spring flush of pasture growth when herbage is most nutritious.

Experiment 4 demonstrated that even the limited grazing available within a fold supplied appreciable quantities of carotene to the laying hen. The young, leafy herbage maintained by frequent gang-mowing was probably richer in carotene than the more mature herbage on the area cut for silage [7], and birds grazing this mature herbage may not have obtained sufficient carotene for maximum egg production. Because of its higher carotene and crude-protein, and lower crude-fibre content, quickly grown leafy herbage is more valuable to poultry than mature herbage. In Great Britain it is difficult to maintain pasture in a young leafy condition during summer drought and in winter, and during these periods the ration should be supplemented with vitamin A. Vitamin D should also be included in the ration during winter, when the birds may receive insufficient sunlight.

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REFERENCES

1. G. S. Robertson and R. G. Baskett, *J. Min. Agric. N. Ireland*, 1929, **2**, 1.
2. J. H. Prentice, ibid., 1933, **4**, 116.
3. R. B. Shaw and E. W. Nightall, *World Poultry Sci. J.*, 1951, **7**, 202.
4. K. J. Carpenter, J. Duckworth, and G. M. Ellinger, *J. Agric. Sci.*, 1954, **44**, 340.
5. D. E. Eyles and S. J. Cowlishaw, *Proc. World Poultry Sci. Congr.*, 1959 (in press).
6. D. C. Kennard, L. E. Thatcher, and V. D. Chamberlin, *Fm. Home Res. Bull. Ohio Agric. Expt. Sta.*, No. 215, 1948.
7. R. Waite and K. N. S. Sastry, *Empire J. Expt. Agric.*, 1949, **17**, 179.

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